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Journal

of

THE ROYAL AERONAUTICAL SOCIETY

JUNE 1960

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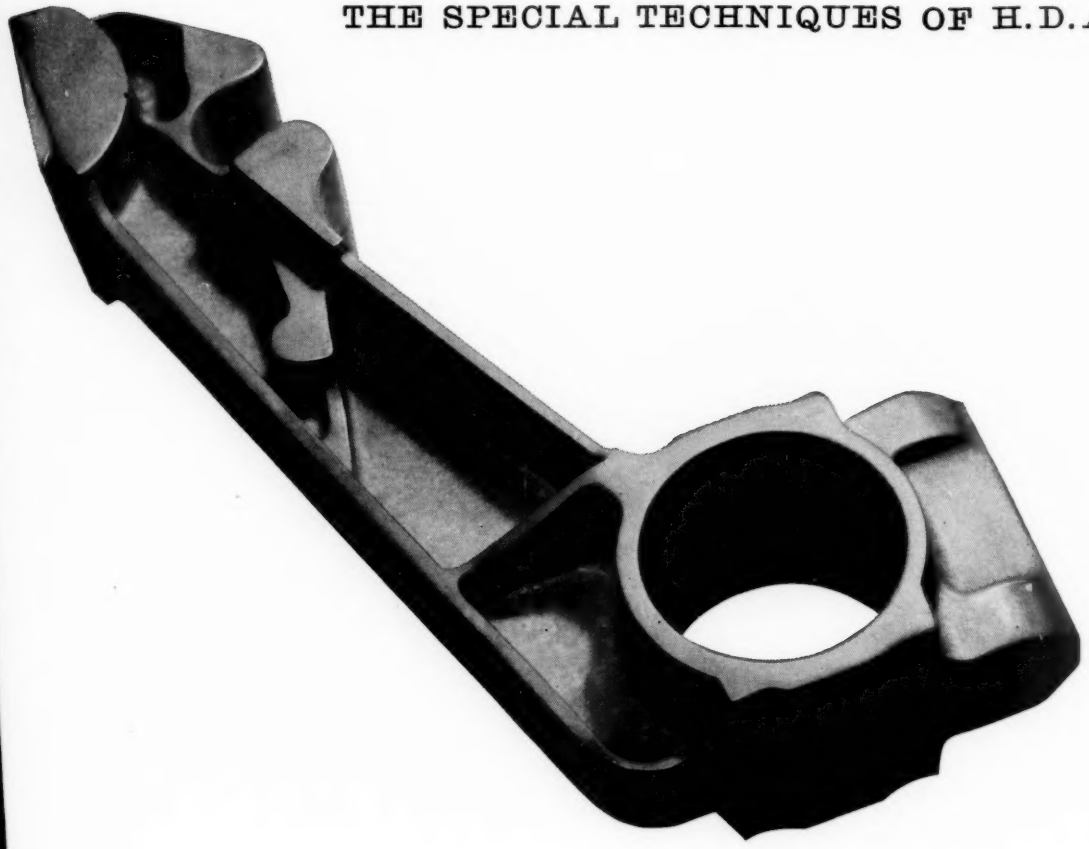

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PUBLISHED MONTHLY AT

4 HAMILTON PLACE, LONDON, W.1

Telephone: Grosvenor 3515-9 *Telegrams:* Didaskalos, Audley, London

SUBSCRIPTIONS: £7 10s. 0d. PER ANNUM, PLUS 9s. POSTAGE AND PACKING
SINGLE COPIES: 12s. 6d. PLUS 9d. POSTAGE AND PACKING

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All communications for publication in the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., F.R.Ae.S., Hon.F.C.A.I., F.I.A.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

ADVERTISEMENT OFFICE: *One Arundel Street, Strand, London, W.C.2 Covent Garden* 1612.

PRINTED BY THE LEWES PRESS, WIGHTMAN & CO. LTD., LEWES, SUSSEX, ENGLAND, AND PUBLISHED BY THE ROYAL AERONAUTICAL SOCIETY, 4 HAMILTON PLACE, LONDON, W.1, ENGLAND

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NOTICES

President of the Society 1960-1961

Dr. E. S. Moult, President of the Society for the year 1960-1961 took Office at the Annual General Meeting held on Thursday 5th May 1960.

President-Elect

Air Marshal Sir Owen Jones, K.B.E., C.B., A.F.C., B.A., D.I.C., F.R.Ae.S., M.I.Mech.E., R.A.F. (Retd.), has been elected President-Elect of the Society for 1961-62.

Vice-Presidents

The following have been elected Vice-Presidents of the Society for 1960-61:—

Air Commodore F. R. Banks, C.B., O.B.E., C.G.I.A., F.R.Ae.S., Hon.F.I.A.S., M.I.Mech.E.

Professor A. R. Collar, M.A., D.Sc., F.R.Ae.S., F.I.A.S.

B. S. Shenstone, M.A.Sc., F.R.Ae.S., F.C.A.I., A.F.I.A.S.

Council for 1960-1961

The following are the newly elected Members of Council as a result of the Ballot declared at the Annual General Meeting held on Thursday 5th May 1960.

Dr. R. Cockburn (*Associate Fellow*)
*Sir William Farren (*Hon. Fellow*)
*L. G. Frise (*Fellow*)
Dr. G. S. Hislop (*Fellow*)
*M. B. Morgan (*Fellow*)
N. E. Rowe (*Fellow*)
Air Marshal Sir Herbert D. Spreckley (*Fellow*)

*Re-elected.

Annual General Meeting and General Meeting

The Annual General Meeting of the Society was held at 4 Hamilton Place, London W.1, on 5th May 1960.

The President, Mr. Peter Masefield, first presented a number of Prizes and Awards for papers published by the Society during the past year. *See* pp. XXXII-IV.

The Annual Report and Balance Sheets of the Royal Aeronautical Society and Aeronautical Trusts Limited for 1959 were approved. During the discussion on the Annual Report attention was drawn to an error in the first paragraph of the item on new By-Laws, page 234 of the April 1960 Journal where it was stated that the amendments to the new By-Laws were passed at "General Meetings of members held on 3rd December 1958 and 4th May 1959." The meeting on 3rd December dealt solely with the question of the increased Annual Subscriptions and the paragraph in the Annual Report should read as follows:

> "The Privy Council have ratified the amendments in the Society's By-Laws which were passed at a General Meeting of Members held on the 4th May 1959."

A discussion ensued regarding the time of the Annual General Meeting and the question was put to the Vote. It was agreed that in future the Annual General Meeting should be held at 6.30 p.m.

The General Meeting of Voters of the Society was held immediately after the Annual General Meeting and the following resolution was passed unanimously:

"That the definition of the words "The Society" in By-Law 1 of the By-Laws allowed the 11th of January 1960 be amended by adding the words "and the Helicopter Association of Great Britain" after the words "Institution of Aeronautical Engineers."

The retiring President, Mr. Peter G. Masefield, then handed over his Presidential Badge to the incoming President, Dr. E. S. Moult. Mr. Masefield thanked the Council, the Members of the Society and the Staff of the Society for the support he had received during his term of office. Dr. Moult paid a warm tribute to Mr. Masefield for all that he had achieved in the past year and presented him with a shield showing the Society's crest and recording his term of office.

Garden Party

As mentioned in the Annual Report (April Journal) the Society will not have a Garden Party this year.

Honorary Fellows

Honorary Fellowship, the highest honour the Society can confer, has been awarded to the following:—

Professor W. J. Duncan, C.B.E., D.Sc., F.R.S., F.R.Ae.S. (Professor of Aeronautics and Fluid Mechanics at the University of Glasgow and Chairman of the Aeronautical Research Council).

Sir George Edwards, C.B.E., B.Sc., F.R.Ae.S., Hon. F.I.A.S. (Managing Director of Vickers-Armstrongs (Aircraft) Ltd., and a Past-President of the Society).

Honours Awarded to Members

Sir Harold Roxbee Cox, *Fellow*, has been made a Fellow of the Imperial College of Science and Technology.

International Congress and Exposition of Automotive Engineering

The Society of Automotive Engineers will hold an International Congress and Exposition of Automotive Engineering in Detroit, Michigan from 9th to 13th January 1961.

Members of the Royal Aeronautical Society are invited to submit papers for presentation at the Congress. The subjects in which papers are requested are as follows:—

Combustion Research for Piston Turbine Engines and Rockets; Air Cargo Loading Systems (Sub-topic: Alternative methods of loading and stowing, special equipment requirements and economics for various types of service); Advances in Airport Design; Blind Landing and Approach Systems for Conventional Aircraft; Recent Developments in High-Temperature Anti-Friction Bearings and their Lubrication; High-Strength, Extreme-Temperature Structures; Ground Support Equipment for Aircraft (such as starters, refuelers, etc.); Propulsion Drive Lines for V/STOL Aircraft (Sub-topic: Including cross-shafting over-running clutches and gears for multi-engine installations); Application of Nuclear Radiation for Production Control; Effects of High-Energy Radiation on Materials of Engineering Interest; Manufacturing Processes (Sub-topic: Special forging machines; Cold forming); Automation (Sub-topic: Degree of integration of operations into a single transfer machine; partial automation such as automatic loading and unloading of single machines); Fuel Cells; High Speed Wheel and Brake Design and Maintenance; Application of Nuclear Radiation for Research and Development.

Members who would like further details should write to the Secretary, Royal Aeronautical Society, 4 Hamilton Place, London W.1, as soon as possible as the S.A.E. had hoped to have summaries of proposed lectures by the **end of June.** Final manuscripts are not required until the end of October 1960.

Acknowledgment

The Council wish to acknowledge a number of items which have been given to the Library by Miss M. Baldwin, 49 Acacia Road, London N.W.8. These include an album of "early days" photographs, early flying meeting programmes, illustrated newspapers and "amateur" accounts of the Rheims and Bournemouth meetings by Miss Baldwin's mother whose brother was Douglas White of the firm which built the Norman Thompson Aircraft.

Essay Competitions

Full details for the Waverley Gold Medal and Application in Industry Essay Competitions may be obtained from the Editor, *Research*, 4/5 Bell Yard, London W.C.2. The last date for entry is 31st July 1960.

LECTURE THEATRE APPEAL

The following lists show further donations received up to the time of going to press.

Donations

Previous total (after minor adjustments)	£14629	12	3
A. Akers, Esq.	1	0	0
P. Anfield, Esq.	1	0	0
Lt. W. H. Atwood, R.C.N.	1	1	0
D. E. H. Balmford, Esq.	2	0	0
H. Barrett, Esq.	1	0	0
F. Beach, Esq.	2	0	0
R. W. Billington, Esq.	1	1	0
G. H. Binns, Esq.	1	1	0
E. G. Broadbent, Esq.	3	0	0
Brough Branch	25	17	0
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R. L. Carstaires, Esq.	2	0	0
N. D. C. Clifton, Esq.	1	1	0
W. B. Coles, Esq.	5	0	0
J. R. Cook, Esq.	2	0	0
J. G. H. Cooper, Esq.	1	0	0
P. N. Cornall, Esq.	2	0	0
D. I. Cowie, Esq.	1	1	0
W/O J. Crampton	1	1	0
W. A. Crane, Esq.	1	1	0
Cullum Detuners Ltd.	10	10	0
R. M. Dakin, Esq.	2	0	0
J. E. Dibley, Esq.	2	0	0
D. R. H. Dickinson, Esq.	1	1	0
Wg. Cdr. K. J. B. Dunlop	2	0	0
W. K. Dunlop, Esq.	2	0	0
Lt. Col. A. T. Eadon	5	5	0
C. R. Elgie, Esq.	1	1	0
C. Ellam, Esq.	2	0	0
E. E. Fenn, Esq.	3	3	0
Sq. Ldr. J. Ford	3	0	0
Lt. Col. A. P. H. B. Fowle	2	2	0
M. C. Frengley, Esq.	2	5	0
N. M. Gemson, Esq.	2	0	0
L. S. Greenland, Esq.	5	5	0
Halton Branch (This donation includes the Residue of the Laurence Deane Memorial Trophy Fund)	26	5	0
P. G. E. Hand, Esq.	2	2	0
D. A. J. Harben, Esq.	2	2	0
Hatfield Branch	30	0	0
Henlow Branch	40	0	0
R. Hickling, Esq.	3	0	0
C. F. Hill, Esq.	5	0	0
D. Lawler, Esq.	2	2	0
D. B. Leason, Esq.	2	0	0
P. Lloyd, Esq.	3	0	0
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R. S. Martin, Esq.	2	0	0
C. L. Munro, Esq.	1	1	0
V. D. Naylor, Esq.	1	1	0
T. R. Nelson, Esq.	5	0	0
New Zealand Division	250	0	0
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K. W. Sambell, Esq.	1	1	0
William Samuel & Co.	15	15	0
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Southend Branch	5	0	0
Swindon Branch	25	0	0
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Flt. Lt. D. Woods	1	10	0
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M. Woolley, Esq.	2	5	0
G. A. Yarotoski, Esq.	5	0	0
	592	15	4
	£15222	7	7

7-Year Covenants

Previous total (after minor adjustments)	£5071	12	10
A. J. K. Carline, Esq.	1	0	0
L. J. Charley, Esq.		5	0
J. F. Cuss, Esq.		10	0
Fairey Aviation Ltd.	357	3	0
R. T. Jones, Esq.	10	0	
P. H. Mabey, Esq.	5	0	
C. A. Partridge, Esq.	7	6	
C. V. Symons, Esq.	5	0	
	360	5	6
	*£5431	18	4

**With Income Tax at the present standard rate of 7s. 9d. in the £ this figure should produce £62080 (approx.) over the 7-year period.*

10-Year Covenants

Previous Total	*£1612 10 0

With Income Tax at the present standard rate of 7s. 9d. in the £ this figure should produce £26325 (approx.) over the 10-year period.

Annual Payments (unspecified period)

Previous total	£83	8	0
G. E. Lee-Steer, Esq.	2	2	0
	£85	10	0

GRAND TOTAL (approximately) £107,705

Further promises amounting to £647 (approx.) had been received up to the time of going to press, and donations in kind promised by firms are valued at £3500 (approx.)

The following have also subscribed but do not wish the amounts of their contributions to be published:—

R. S. Close, Esq.
A. R. Guy, Esq.
J. Harris, Esq.
J. C. Hunsaker, Esq.
Gp. Capt. A. K. Hunter
E. Dixie Keen, Esq.
G. Panley, Esq.

Supplement to Oxford English Dictionary

The following is the seventh list of aeronautical terms for the Supplement to the Oxford English Dictionary for which assistance in tracing early references is required. If members know of an earlier use of any word in the following list they are asked to write to the Editor, Oxford English Dictionary Supplement, 40 Walton Crescent, Oxford, giving the reference(s), date, author, title, chapter and page.

carrier (=aircraft carrier)	1931	*Flight*, 30th January
carrier-based	1935	*Flight*, 9th May
carrier-borne	1939	K. Edwards, *Navy of Today*
catapult, v. (in launching aircraft)	1931	*Air Annual of the British Empire*
chine (in flying boats)	1920	*Journal of the Royal Aeronautical Society*, XXIV, 465
chute (=parachute)	1920	*The Ace* (Los Angeles), 15th April
clean, adj. (=streamlined; of aircraft)	1916	H. Barber, *The Aeroplane Speaks*
clean, v. (as above)	1931	*Flight*, 16th October
cleanness (of aircraft design)	1931	*Flight*, 2nd January
climb, sb. (Aviation)	1916	H. Barber, *The Aeroplane Speaks*
climbing, vbl. sb. (Aviation)	1913	Claude Grahame-White, *Aviation*
clipper (aircraft)	1933	*Flight*, 19th January
co-axial propellers	1938	*Journal of the Royal Aeronautical Society*, XLII, 646
contra-prop	1940	*Times*, 28th March
contrapropeller	1939	*Journal of the Royal Aeronautical Society*, XLIII, 109
control room	1934	*Times*, 24th October
control tower	1930	*Daily Express*, 6th October

It has proved impossible to obtain copies of some works, now out of print, which would help in the preparation of the Supplement. Anyone willing to give, sell or lend (for a protracted period) copies of the following is asked to write to the Editor at Oxford.

1918	H. J. Stephens	*Glossary of Aeronautical Terms and Phrases*
1918	W. E. Dommett	*Dictionary of Aircraft*
1919	W. B. Faraday	*Glossary of Aeronautical Terms* (Royal Aeronautical Society)
1919	H. Shaw	*Textbook of Aeronautics*
1919	C. C. Turner	*Struggle in the Air* 1914-18

The Society would also like to acquire copies of Stephens, Dommett and Turner.

MAN POWERED AIRCRAFT GROUP

In September 1958, the Council agreed to the formation of Groups within the Society and in February 1959, the Man Powered Aircraft Group was formed. Since that time, the MPAG Steering Committee has met regularly and has discussed ways and means whereby the objects of the Group might be advanced.

During the Session October 1959/April 1960, a number of interesting lectures were arranged and these were included in the Society's Lecture Programme.

In November 1959, Mr. Henry Kremer offered a prize for a successful controlled flight of a Man Powered Aircraft and the Regulations and Conditions for the Kremer Competition were published in the February 1960 JOURNAL. Since the publication of these Regulations a number of enquiries have been received from people interested in building a man powered aircraft.

In recent months, the Committee have received funds for the advancement of the objects of the Group, amounting to £1,100. Of this sum, £1,000 has been donated by Air Commodore J. G. Weir, *Fellow* of the Society. This generosity has encouraged the Group in its work and the President and Council would like to take this opportunity of thanking Air Commodore Weir for his encouragement. The additional £100 has been contributed by members of the Committee.

The Committee hope that further contributions will be made to further the work of the Group.

At its last meeting the Committee received the following Resolution from the Council of the Society:—

"The Man Powered Aircraft Group of the Royal Aeronautical Society, by permission of the Council of the Society, is empowered to consider financial contributions to one or more persons or organisations who submit promising projects for man powered aircraft. Such financial contributions to be within the means available to the Group and subject to each award being individually approved by the Finance Committee of the Society."

With the receipt of such funds, the Committee have now drawn up regulations, so that grants may be made to individuals or organisations, fulfilling the conditions as listed opposite.

Man Powered Aircraft Group Committee

MR. H. B. IRVING (*Chairman*)
MR. R. GRAHAM
MR. J. M. GRAY
MR. R. P. ITTER
MR. G. LILLEY
MR. A. NEWELL
MR. T. R. F. NONWEILER
MR. D. RENDEL
MR. PETER SCOTT
MR. B. S. SHENSTONE
DR. D. R. WILKIE

Members of the Society interested in joining the Group should write to the Secretary of the Society.

CONDITIONS GOVERNING GRANTS

1. The Royal Aeronautical Society (Man Powered Aircraft Group) will consider making financial contributions to one or more persons or organisations who submit promising projects designed to further the achievement of Man Power Flight.

2. Submissions must contain as much detailed information as possible and, for example, in the case of a project for a complete aircraft, should include the following and any other information which the submitting person or organisation considers relevant.

(*a*) General description of the project in simple terms; describing particularly the more interesting or unusual features.
(*b*) Three-view drawing of the project at 1/24 scale or larger.
(*c*) Weight breakdown of structure, drive mechanism, controls, equipment and crew weight.
(*d*) An analysis of project to be given, including drag and power requirements, preferably in graphical form, covering the range from zero speed to cruising speed.
(*e*) Descriptive analysis of method of propulsion (*e.g.* propeller or flapping wings).
(*f*) Stressing assumptions (including *V-n* diagram).
(*g*) Calculations to show the duration of flight and manoeuvrability to be expected.
(*h*) Estimated total financial outlay required for the project in as much detail as possible and also the monthly financial requirements throughout the duration of the job. These must be based on total costs and not upon any contribution which the Royal Aeronautical Society would be expected to make.
(*i*) A progress plan against time from the initiation of the project to the completion of initial flight tests. This plan should be in the form of stages; *e.g.* completion of wing, fuselage, etc.

3. Submissions must reach the Royal Aeronautical Society not later than 31st October 1960.

4. Submissions will not be paid for by the Royal Aeronautical Society and will remain the property of the person or organisation making the submission. Submissions will be kept by the Royal Aeronautical Society until decisions on contributions are made.

5. On any question regarding the suitability of submissions for contributions, the decision of the Royal Aeronautical Society shall be final.

6. If requested, representatives of those submitting projects will attend a round-table meeting held by the Royal Aeronautical Society at which the features of the various designs submitted will be discussed. Such meeting would take place before any contributions from the Society are announced.

7. Any such contribution would not debar the recipient from entry for the Kremer Competition.

LIBRARY

Members may like to know that Abbott and von Doenhoff's *Theory of Wing Sections* which has been out of print for some years is now available again as a Dover Publications production. The distributors in this country are Constable and the price is 24s. While errors in the original edition have been corrected, no extensive rewriting has been undertaken.

COURSE ON AUTOMATIC PRODUCTION AND CONTROL

The Department of Aircraft Economics and Production, The College of Aeronautics, will hold a short course on Automatic Production and Control from 11th to 22nd July 1960. Application forms may be obtained from The Department of Aircraft Economics and Production, College of Aeronautics, Cranfield, Bletchley, Bucks.

MEDALS AND PRIZES OF THE SOCIETY

The following Medals of the Society awarded by the Council were presented by Dr. E. S. Moult, C.B.E., B.Sc.(Eng.), F.R.Ae.S., M.I.Mech.E., President 1960-61, at the Wilbur Wright Memorial Lecture on 19th May 1960. The Scrolls of Honorary Fellowship were also presented on this occasion.

The Society's Gold Medal—the highest honour the Society can confer for work of an outstanding nature in Aeronautics—to:

Sir Frederick Handley Page, C.B.E., F.C.G.I.,
Hon.F.R.Ae.S., Hon.F.I.A.S., Hon.M.Inst.T.
Chairman and Managing Director,
Handley Page Ltd.

"for his outstanding contributions to British aircraft design for more than fifty years."

The Society's Silver Medal—awarded for work of an outstanding nature in Aeronautics—to:

R. H. Chaplin, O.B.E., B.Sc., F.R.Ae.S.
Executive Director and Chief Designer
of Hawker Aircraft Limited

"for his achievements in the design and development of military aircraft."

The Society's Bronze Medal—awarded for work leading to an advance in Aeronautics—to:

H. G. R. Robinson, B.Sc., A.C.G.I.
Ballistic Missiles Group, Royal Aircraft Establishment

"for his work leading to practical achievement in ballistic missiles."

The British Gold Medal for Aeronautics—awarded for outstanding practical achievement leading to advancement in Aeronautics—to:

B. E. Stephenson, F.R.Ae.S.
Director of Engineering, Vickers-Armstrongs
(Aircraft) Limited

"for his outstanding practical achievements in aircraft design and development."

The British Silver Medal for Aeronautics—awarded for practical achievement leading to advancement in Aeronautics—to:

Philip A. Wills, C.B.E., A.F.R.Ae.S.
Chairman, George Wills and Sons Ltd.

"for his practical achievements in the service of British gliding."

The Wakefield Gold Medal—awarded for contributions towards safety in aviation—to:

E. G. Broadbent, M.A., F.R.Ae.S.
Royal Aircraft Establishment

"for his contribution to aircraft safety through the theory of aeroelasticity."

The R. P. Alston Medal—awarded for practical achievement associated with the Flight Testing of Aircraft—to:

Wing Commander R. P. Beamont, R.A.F.O., O.B.E.,
D.S.O., D.F.C., A.R.Ae.S.
Manager of Flight Operations and Chief Test Pilot,
English Electric Aviation Limited

"for his practical achievements in flight testing supersonic aircraft."

The N. E. Rowe Medals—awarded for the best lecture given before any Branch of the Society by a member of a Branch—for two age groups, (*i*) between 21 and 26 years of age and (*ii*) under 21 years —to:

C. J. Wood, B.Sc.(Eng.), A.C.G.I., Grad.R.Ae.S.
Imperial College of Science and Technology

"for his lecture 'Transonic Buffeting on Aerofoils'" (21-26 years)

and

J. A. Miller
Hull Technical College

"for his paper 'A History of the Development of Flight Refuelling'" (under 21 years of age).

Note: Mr. Wood received his Medal at the Annual General Meeting of the Society on 5th May 1960 as he was unable to be present on 19th May.

The following Medals and Prizes of the Society, awarded by the Council, were presented by the retiring President, Mr. Peter G. Masefield, M.A., F.R.Ae.S., Hon.F.I.A.S., M.Inst.T., at the Annual General Meeting on 5th May 1960:—

The Simms Gold Medal, for the most valuable contribution read before, or received by, the Society on any subject allied to aeronautics—to:

D. J. Farrar, O.B.E., M.A., F.R.Ae.S.
Chief Designer (Guided Weapons), Bristol Aircraft
Limited,

for his paper "The Bloodhound." (January 1959 JOURNAL.)

The George Taylor (of Australia) Gold Medal, for the most valuable contribution read before, or received by, the Society on aircraft design, manufacture and operation—to:

R. Hafner, F.R.Ae.S.
Formerly Chief Designer (Helicopters) Bristol Aircraft Limited—now Special Director (Bristol) Westland Aircraft Limited,

for his paper "Safe Mechanisms." (May 1959 JOURNAL.)

The Edward Busk Memorial Prize, for the most valuable contribution published in one of the Society's publications on Applied Aerodynamics—to:

E. C. Maskell, M.A., A.F.R.Ae.S. and
Dr. J. Weber, A.F.R.Ae.S.
Aerodynamics Department, Royal Aircraft Establishment,

for their paper "On the Aerodynamic Design of Slender Wings." (December 1959 JOURNAL.)

The Orville Wright Prize, for the most valuable contribution to "THE AERONAUTICAL QUARTERLY" of the Society on some subject of a technical nature in connection with aeronautics—to:

R. Hicks, Ph.D., M.Sc.
G.E.C. Simon-Carves Atomic Energy Group,

for his papers "Asymmetrically Plate-Reinforced Circular Hole in a Uniformly End-Loaded Flat Plate" and "Symmetrically Loaded Circular Plates under the Combined Action of Lateral and End Loading." (May and August 1959 QUARTERLY.)

The Herbert Ackroyd Stuart Memorial Prize, for the most valuable contribution to the Society's publications on aircraft propulsion—to:

P. Lloyd, C.B.E., M.A., F.R.Ae.S.
Deputy Director, National Gas Turbine Establishment,

for his paper "Some Aspects of Engine Noise." (September 1959 JOURNAL.)

The J. E. Hodgson Prize, for the best paper of a general nature, with emphasis on historical work, published by the Society—to:

Professor A. R. Collar, M.A., D.Sc., F.R.Ae.S., F.I.A.S.
Sir George White Professor of Aeronautical
Engineering, University of Bristol,

for his paper "Aeroelasticity—Retrospect and Prospect." (January 1959 JOURNAL.)

The Branch Prize, for the best paper on an aeronautical subject read before the Branches of the Society and published in the Society's publications—to:

Professor A. W. Morley, M.Sc., Ph.D., Whit.Sch.,
A.C.G.I., F.R.Ae.S.
Formerly Forward Projects Engineer, D. Napier and Son Limited—now Professor of Applied Mechanics, Royal Naval College, Greenwich,

for his paper, given before the Luton Branch of the Society "Notes on Air Breathing Engines for Supersonic Flight." (January 1959 JOURNAL.)

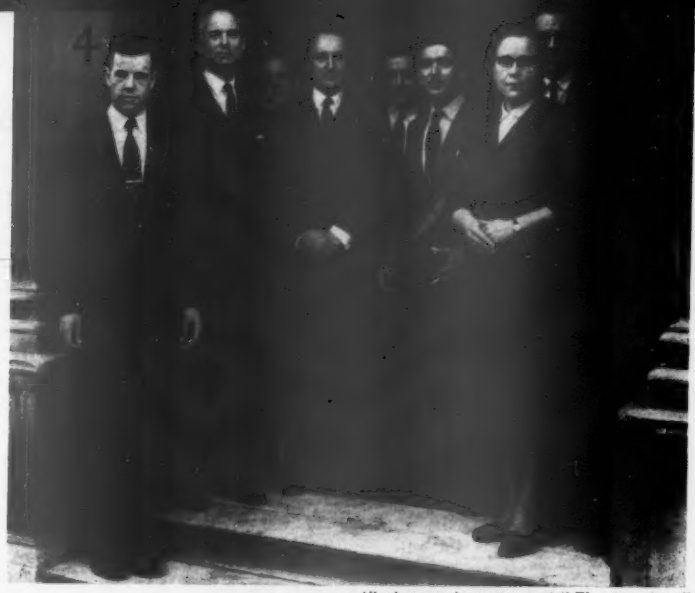
The Navigation Prize, for the best paper on navigation, including meteorological instruments and test equipment, published by the Society—to:

E. G. C. Burt
Guided Weapons Department,
Royal Aircraft Establishment,

for his paper "Theoretical Principles of Guided Missile Systems." (August 1959 JOURNAL.)

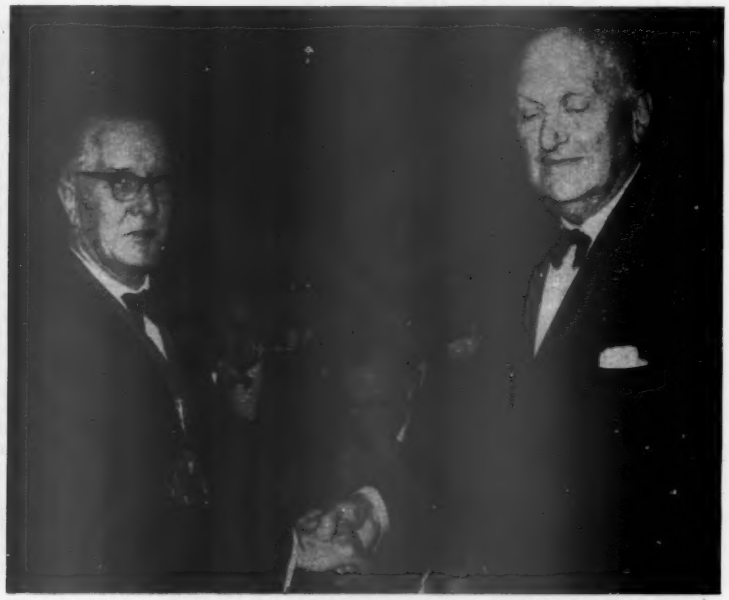
Continued on p. XXXIV

The incoming President, Dr. E. S. Moult wearing his badge of office and the retiring President Mr. Peter G. Masefield, holding the shield with the Society's crest.



(*Right*) Some of the prize winners photographed in the doorway of 4 Hamilton Place after the Annual General Meeting and Presentation of Prizes on 5th May. From left to right, Mr. C. J. Wood, Professor A. W. Morley, Mr. C. L. Bore, Mr. R. Hafner, Mr. P. Lloyd, Mr. E. G. C. Burt, Dr. J. Weber and Mr. E. C. Maskell.

All photographs courtesy of "The Aeroplane."



Presentation of Awards on 19th May 1960—(*from left to right*): Professor W. J. Duncan, *Honorary Fellowship;* Sir George Edwards, *Honorary Fellowship;* The President, Dr. E. S. Moult, after presenting Sir Frederick Handley Page, Hon.F.R.Ae.S., with the *Society's Gold Medal.*

(*Below*) R. H. Chaplin, F.R.Ae.S., the *Society's Silver Medal;* H. G. R. Robinson, the *Society's Bronze Medal;* B. E. Stephenson, F.R.Ae.S., the *British Gold Medal;* Wing Commander R. P. Beamont, A.R.Ae.S., the *R. P. Alston Medal.* Unfortunately photographs were not obtained of Mr. E. G. Broadbent and Mr. Miller. Mr. Wills was unable to be present at the Lecture and received his Medal at the Council Dinner.

MEDALS AND PRIZES—*Continued*

The Usborne Memorial Prize, for the best contribution to the Society's publications written by a Graduate or Student of the Society on some subject of a technical nature in connection with aeronautics—to:

D. G. Drake, B.Sc., Grad.R.Ae.S.
Department of Applied Mathematics,
University of Liverpool,

for his paper "Quasi-Steady Derivatives for the Subsonic Flow Past an Oscillating Aerofoil in a Porous Wind Tunnel." (August 1959 QUARTERLY.)

The Pilcher Memorial Prize, for the most valuable paper read by a Graduate or Student of the Society during the previous year at any meeting of the Society or its Branches—to:

C. L. Bore, B.Sc.(Eng.), Grad.R.Ae.S.
Project Office, Hawker Aircraft Limited,

for his paper "Some Practical Aspects of Kinetic Heating Calculations." (November 1959 JOURNAL.)

NEWS OF MEMBERS

H. L. BARNES (*Associate*) formerly in the Design Office of the de Havilland Engine Co. Ltd. (Rocket Division), is now in the Technical Department, Dunlop Rubber Company (Aviation Division), Coventry.

Sqn. Ldr. L. BYRAM (*Associate Fellow*) formerly at the Directorate of Guided Weapons (Air), Ministry of Aviation, has been posted to the R.A.F. Staff College, Andover.

J. P. DE VALL (*Associate*) formerly Senior Service Engineer, D. Napier and Son Ltd., is now a Senior Service Engineer, Napier Engines, U.S.A.

L. A. FLORENDIS (*Companion*), has been elected President of Old Greek Veterans in Cairo and decorated with the Greek Silver Cross, Order of Phoenix.

W. D. GAFFNEY (*Associate*) formerly Assistant Distribution Manager, Khanaqin Oil Co. Ltd., is now a Senior Lubrication Engineer, British Petroleum Co. Ltd., London.

W. J. GREED (*Associate*) formerly Aviation Manager, Carlux, Chester, is now Technical Aircraft Equipment Representative, Associated Electrical Industries Ltd., in the North Western Region.

A. H. C. GREENWOOD (*Associate Fellow*) was recently appointed to the Board of Vickers-Armstrongs (Aircraft) Ltd., as Director (Sales and Service).

Flt. Lt. S. R. HAWKEY (*Associate*) formerly Senior Trials Engineer, Fairey Aviation Ltd., is now a Reliability Engineer in the Inertial Navigation Division, Elliott Bros. (London) Ltd., Borehamwood.

P. C. HOLDORF (*Student*) having completed his Post Graduate Training with Vickers-Armstrong (Aircraft) Ltd., is now in their Guided Weapons Department at Weybridge as an Electronics Engineer.

D. IREDALE (*Graduate*) formerly a Design Engineer, Weapons Research Department, A. V. Roe and Co. Ltd., is now an Engineer, Projects Department, English Electric Aviation Ltd., Warton.

ADMIRAL SIR CASPAR JOHN (*Associate Fellow*) has been appointed First Sea Lord.

A. V. LEAKE (*Associate*) formerly Dunlop Aviation Representative at Blackburn Aircraft Ltd., will become Dunlop Aviation Resident Engineer in Brazil on 1st July.

P. B. S. LISSAMAN (*Graduate*) formerly Design Stressman, Bristol Aircraft Ltd., is now Assistant Professor of Aeronautics at the U.S. Naval Postgraduate School, Monterrey, California.

B. A. G. MACGOWAN (*Associate Fellow*) formerly Assistant Systems Engineer, de Havilland Engine Co. Ltd., is now Sales Project Engineer (Electric Controls), Sales Department, de Havilland Propeller Co. Ltd.

J. V. ROBERTS (*Associate Fellow*) formerly Helicopter Simulator Engineer, Short Brothers and Harland Ltd., is now Chief Development Engineer for both Beltico Ltd. and Elliott Equipment Ltd., Lisburn, N. Ireland.

D. R. SAMSON (*Associate Fellow*) formerly Chief Stressman, Hunting Aircraft Ltd., Luton, is now Head of the Department of Aeronautical and Mechanical Design, Hatfield Technical College.

J. F. SMITH (*Associate Fellow*) formerly Assistant Installation Engineer, Normalair Ltd., is now Systems Engineer, Air Conditioning Systems, Advanced Projects Group, Hawker Siddeley Aviation Ltd.

L. WALKER (*Associate*) formerly Chief Inspector with Scottish Aviation Ltd., is now with Plessey Co. Ltd., Ilford.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Glenn Nelson Adams
Dennis William Allen
Robert William Avery
William Robert Bryce (*from Student*)
Ernest Bispham Budd
David Robert Carter
Kenneth Frank Currey
Michael Collin William Davy
John Herbert Dolbear (*from Associate*)
John Frederick Greenfield
John Henry Harriss
John Lovejoy Johnston (*from Graduate*)
Edmund Frederick Maillard
Richard Henry Mathews (*from Graduate*)
Kenneth Henry Mitchell (*from Graduate*)
David Pearson
Leonard James Rogers (*from Graduate*)
Peter Greenwood Smith
Michael James Somers Somervell (*from Graduate*)
Trevor Farnham Wick
Dennis Woods (*from Associate*)
Harry Woolstencroft

Associates

Clement Richard Bateman
Ryszard Stefan Browne
John Percival de Vall
William Edger
Douglas Arnold Hawley
George Ronald Gray Henderson
Joseph Hinde
Richard Charles Hotton (*from Student*)
Cecil William Lippiatt
William Charles Edwin Loftus
George Magee
Graham Meyrick
John George Peter Morton
John Sidney Neale
William Burns Petrie
John Leslie Price
Kenneth Leonard Sapsed
Charles Leonard Masson Scott
Cyril Walter William Turner
Henry Matthew Turner
Sam Hey Whitworth

Graduates

Peter Fritz Franz Arnfeld (*from Student*)
Arthur Stuart Blears (*from Student*)
Derek Standring Brown
John William Chapman
Keith Frederick Scott Chard (*from Student*)
David Graham Cutts
Ronald Eaton (*from Student*)
Clive Raymond Foster (*from Student*)
John Foxon (*from Student*)
Robert Jennings (*from Student*)
Ian Drummond Lawrie (*from Student*)
Norman Denis Newton
Barry Pitchfork (*from Student*)
Arnold Frederick Schofield (*from Student*)
John Nigel Waddington (*from Student*)
Christopher Edward Wainwright (*from Student*)
Peter Miles Watkiss (*from Student*)

Students

Ronald Wilfred Atkinson
Colin Richard Beavis
Ian Don Clapp
John Michael Eagle
Roger Fairley
Djordje Kerac
Charles Beech Gordon Masefield
David Alan Needham
Jeffery Brian Newton
Vernon Francis Nicholas
Donald William Nott
David William Ramsay
David William Rotchell

Companions

John Wakeling Baker
John Alan Barke
David Dutton Budworth
William Lambert Edmund Henery
Solomon Kehela (*from Student*)
Douglas Leslie Shears
Clive Parker Wright

The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

VOLUME 64 JUNE 1960 NUMBER 594

Supersonic Aircraft—Promise and Problems

by

M. B. MORGAN, C.B., M.A., F.R.Ae.S.

(Scientific Adviser to the Air Ministry)

The 1,157th lecture to be given before the Society, "Supersonic Aircraft—Promise and Problems" by M. B. Morgan, Esq., C.B., M.A., F.R.Ae.S., Scientific Adviser to the Air Ministry, was given on 17th March 1960, at the Institution of Mechanical Engineers. Mr. Peter G. Masefield, M.A., F.R.Ae.S., Hon.F.I.A.S., M.Inst.T., President of the Society, presided. Opening the meeting Mr. Masefield said he thought this would be one of the most interesting and stimulating lectures of the session. The subject of the supersonic aeroplane had been freely discussed in the United States and probably in Russia also. In this country they had been more reticent so he hoped they would have a really good discussion after this lecture. One significant point was that people no longer wondered whether a supersonic transport could, or should, be built but only whether it should cruise at a Mach number of 2 and be made in light alloy, or whether it should be around Mach 3 and be made of steel or more exotic materials. That sooner or later—and many believed sooner—transports would fly at supersonic speeds at 70,000 ft. was taken for granted.

Mr. Morgan was well known to them all. Born in Wales, he was educated at Rutlish, Merton and St. Catharine's College, Cambridge, where he took the Mechanical Sciences Tripos and won the John Bernard Seely Prize in Aeronautics in 1934. In fact, he and Mr. Morgan used to enjoy the Cam together and Mr. Morgan looked little different today than he had in those days. Mr. Morgan was apprenticed to Mather and Platt Ltd. and also spent a short time at Vickers, Weybridge before joining the R.A.E., Farnborough in 1935. Since then he had specialised in aerodynamics, flight research and development, stability and control and, he had taken his Pilot's Licence in 1944. He was Head of the Aero Flight Section of the R.A.E. from 1946-1948, Head of the Guided Weapons Department from 1948-1953 and Deputy Director of the Establishment from 1954 until 1959. He had then been appointed to his present position of Scientific Adviser to the Air Ministry and had also been Chairman of what had come to be known as "STAC"—Supersonic Transport Aircraft Committee. He felt that they could have no better person than Mr. Morgan to talk on the Supersonic Transport.

1. Introduction

"It must be considered that there is nothing more difficult to carry out, nor more doubtful of success, nor more dangerous to handle, than to initiate a new order of things. For the reformer has enemies in all those who profit by the old order, and only lukewarm defenders in all those who would profit by the new."

I could not resist the temptation of opening this lecture on supersonic aircraft with the above Machiavellian quotation—it is indeed quite literally Machiavellian, being taken from "The Prince." Fortunately the aeronautical fraternity, throughout its brief history, has paid little heed to such sentiments. Each time new regimes of flight have been opened up by the pioneers, large scale use of the new territory has followed swiftly and surely; usually at a quicker pace than had been predicted. The jet engine was only born about 20 years ago. Who in those days would have felt confident that within a couple of decades large aircraft carrying upwards of 100 passengers at speeds approaching the speed of sound would be in routine operation over the North Atlantic on a large scale? Yet the big jets are with us, have been on the routes for several years, and are obviously going to dominate long distance travel during the coming decade.

Supersonic flight covers an immense field, ranging from small fighter aircraft through a whole range of pilotless devices—ground and air launched—to ballistic missile re-entry and satellite recovery vehicles. In order to keep my task within bounds, I intend to confine myself to transport aircraft in the medium and long range brackets.

I hope to convince you that we are on the brink of another revolution in the transport aircraft story; that it is quite inevitable that long range aircraft will go very considerably faster during the coming decades, certainly up to two or three times the speed of sound—in quantity and not as occasional prestige freaks; and that an abrupt end of the road in economical speed is not yet within sight.

It may seem a trifle odd to some of you that the

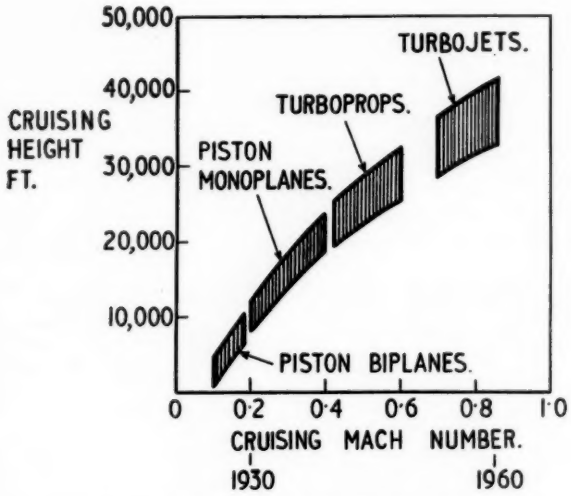


FIGURE 1. The subsonic speed/height pattern.

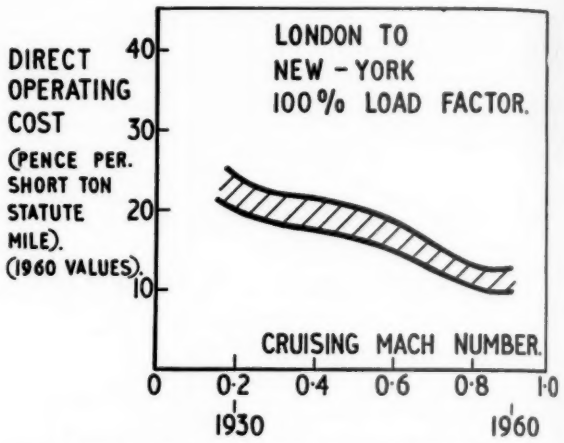


FIGURE 2. The subsonic direct operating cost pattern.

Scientific Adviser to the Air Ministry should be giving tongue on supersonic transport aircraft. May I hasten to add—in order to dispel any deductions about our airmen being much more interested in transports than in fighters, bombers and missiles—that I am a fairly recent import from the Farnborough fields to the Whitehall streets; and that while at Farnborough I had a particularly good opportunity of sampling thought on supersonic transports.

My intention is to touch briefly on the subsonic picture as it unfolded while we were all growing up; to indicate the way in which I believe many of us will see the supersonic picture as it falls into a pattern; and to give some detail on a few of the more interesting or promising parts of that pattern. My thanks are due to the Air Ministry and the Ministry of Aviation for authority to give this lecture. The views expressed, however, are of course, purely personal and in no way official.

2. Subsonic Transports—Past and Present

Figure 1 illustrates the broad speed/height picture for transports in widespread use on the routes during the past four decades. The point to be made here is that the aeroplanes cluster into a number of families, each following the other—biplanes, monoplanes, first with unsupercharged then with supercharged engines, turboprops, and finally the turbo-jets with swept wings. The pattern is by no means fortuitous—each speed and height cluster results from compromises and optimisations made by numerous individual chief designers bearing in mind both straightforward technical parameters and, rather more involved and awkward to quantify, considerations of direct running costs, initial costs, passenger appeal, and the rest. So far, as speed and height have increased, overall costs per passenger mile on the longer ranges have decreased.

This is illustrated in Fig. 2. In consequence the newer themes have tended to drive out the older ones—there are, for example, few biplanes left on the routes—although at any one time there must be a mixture of several different families since, once bought, an aeroplane is expected to last 10 years or so.

From the viewpoint of tidy and easy management it can of course be argued that this changing technical scene is a nuisance. It would obviously be rather nice, having run a fleet of reasonably economical transports for ten years, to order some more of the same when they wore out; possibly improved a little, as a result of routine modifications during service, but basically the same aeroplanes. It might, indeed, be possible to envisage such a state of affairs were the whole of world aviation under single and rugged management. Faced, however, with a number of sovereign states, many with vigorous aircraft design teams and lively air transport organisations, competition for export orders and for fare-paying passengers is inevitable. Unless invention and development run up against a brick wall, radical change from one generation of aircraft to the next must remain the order of the day.

At this stage of the argument railways and ships inevitably crop up. It is pointed out that the trains in general sit on the same gauge tracks and travel at the same speed as they did sixty years ago; while the cruising speed of civil ships has not altered dramatically over the decades. Is it not time, it is asked, that aeroplanes took a hint from this story and paused for consolidation—with consequent easement of the administrative and financial agonies resulting from people insisting on being too clever too quickly; this question is being posed with particular point at the moment as the impact of the big jets is making itself felt on the second hand market for piston-engined machines; aeroplanes which—when built—were thought to have many more years of useful life ahead of them than seems likely now.

The simple answer here is that trains and ships reached their brick wall years ago. The ship picture is the more straightforward to illustrate. If a vessel is floating on water and is then pushed to make it travel on the surface, the resistance to motion increases so rapidly that

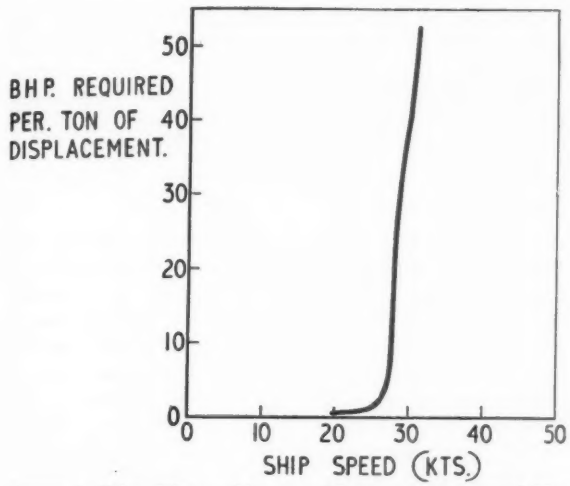


FIGURE 3. Ships. Why cruising speed has not risen appreciably.

on any criterion a stage is reached at which any further increase in speed is grossly uneconomic. Fig. 3 is typical of the sort of diagram that can be drawn; economical travel on the surface has pretty well come to the end of the road in terms of speed. A quite radical departure such as submerging the whole vessel to cut out wave resistance, or making it ride on an air cushion, is awaited.

It used to be thought that aeroplanes would reach their brick wall in the "sonic barrier." Curves, similar to the "ship" curve of Fig. 3 were often drawn, with the skying of the curve at its right hand side corresponding to approach to sonic speed and the generation of "compressibility" drag. The change in our thoughts on future trends for transport aircraft has resulted basically from the development of efficient high speed propulsion systems, combined with intensive aerodynamic work which has converted the sonic barrier into a sonic bump.

Having demolished the sonic "barrier," newly acquired knowledge of aerodynamics, structures, materials and all the sciences and arts relevant to supersonic flight can be applied to evaluate the practicability of not too expensive flight at supersonic speeds. The purpose of putting the subsonic history of Figs. 1 and 2 before you is to suggest that—if supersonic flight is shown to be of the same order of cost as we are used to at present—past experience suggests that the advantages of speed will be seized upon vigorously. Other things being equal, no one wants to sit in an aeroplane longer than he can help.

My main task, in the present paper, is therefore basically to examine whether there is any likelihood of supersonic flying being not only practicable (we all know that it is) but also competitive cost-wise.

Before leaving the subsonic aircraft, two points of relevance to subsequent argument should be mentioned—the influence of size on aircraft economics and the compromise between cruising efficiency and tractable approach and landing characteristics. Both of these points have been studied extensively by the project teams engaged on the design of current long range high subsonic turbo-jet and turbo-prop transports, and when their thoughts turn to supersonic machines their ideas are inevitably coloured by this previous background.

On aircraft size, let us consider the influence of the design figure for passenger load on direct operating costs for a family of aircraft designed for the London/New York run, with jet engines and swept wings, cruising at $M=0{\cdot}85$. Increasing the all-up weight from 150,000 lb. to 250,000 lb. (passengers from 70 to 130) reduces direct operating costs by 30 per cent. The point here is that up to very large all-up weights, direct operating costs continue to fall as size increases. The golden rule for economy seems, in fact, to be *to make the aircraft as big as you dare and fill it*. The cut-off in size comes when the operator is afraid that he cannot use the capacity provided. In the past there has been a tendency for this to be underestimated—once aeroplanes had been built people have been sorry that they were not bigger; stretched fuselages have been very common indeed.

The second point concerns approach speeds. Taking again as an example a family of trans-Atlantic jet transports designed to cruise at $M=0{\cdot}85$, it can be shown that considerable economies are possible by tolerating high approach speeds—since optimising the aeroplane for the cruise results in wing loadings higher than are comfortable for landing. Each time the designer compromises in the direction of lowering the approach speed, by putting on bigger wings than are strictly necessary for the cruise, the economy of the operation suffers. Thus, while limits are finally set by safety and runway performance, the designer has every incentive to sail as near the wind as he dares in terms of keeping up the wing loading and persuading the operator to tolerate high speed on the approach and landing. Although lip service is sometimes paid to the need for aeroplanes which land slow, the effect mentioned is so marked that financial considerations in the end often dominate the issue. Stretched runways have been even more common than stretched fuselages.

3. The Broad Supersonic Picture

3.1. GENERAL

Supersonic transport aircraft can only be considered seriously because of the immense amount of research and development which in recent years has gone into supersonic flight, manned and unmanned, as a result of military needs and funded by military money. The scale at which worldwide flight experience is being amassed at supersonic speeds may not generally be appreciated. In his recent Plesman lecture at Delft, Hall Hibbard estimated that manned aircraft were logging 1,400 hours per day at *supersonic speeds* in the Western world alone; lessons are also being learned from the continual flight testing of anti-aircraft guided weapons, powered bombs, and ballistic missiles—all supersonic and some very highly supersonic. This activity has received—as it must—elaborate backing in the way of aerodynamic, structural and engine test facilities, guidance and control laboratories, and theoretical teams provided with elaborate computational resources.

As part of this international picture, we in this country have not been idle. The achievements of the Fairey Delta

and the Lightning are well known. Following shortly is the still faster Bristol research aircraft, made of steel. On the guided weapon side we have a variety of defensive missiles, both ram-jet and rocket-propelled, designed to operate at several times the speed of sound. We have the supersonic flying bomb. Finally we have for some years been pushing through a ballistic missile programme, and the successful firings of the re-entry test vehicle Black Knight have regularly been in the news.

Behind all this, taking the official Establishments and Industry together, we have our own resources in the way of theoretical teams, supersonic tunnels large and small, shock tubes, kinetic heating structural facilities, turbo-jet, ram-jet and rocket test plants, and so on. It can therefore fairly be claimed that this country is well and truly in the supersonic business—the supersonic military business. If a case can be made for us entering the supersonic civil business, we should be well poised to take the step—since in many of the relevant techniques a new trade has not to be learned overnight.

Let us now deal in a very broad way with some of the technical factors associated with flight in the supersonic region Mach 1·0 to 5·0. The scene is dominated by considerations of engines, aerodynamics and structures.

3.2. PROPULSION

The engine story is illustrated in Fig. 4. Although "supersonic" propellers have had their advocates, no one seriously suggests that propellers can have much part to play once cruising speeds get truly above sonic. In our context the turbo-prop combination is essentially a low speed device. The turbo-jet, on the other hand, likes going fast—with such engines overall efficiency rises with Mach number up to about two and a half times the speed of sound. At this stage, however, cooling difficulties are becoming more acute and engine materials are presenting increasingly difficult problems. At Mach numbers above about 3·0, the ram-jet carries on where the turbo-jet left off. A limit in speed is set by intake considerations and, although year by year ideas have steadily changed on the maximum speed at which it is sensible to consider a reasonably efficient ram-jet/intake combination, present feeling is that between 6·0 and 7·0

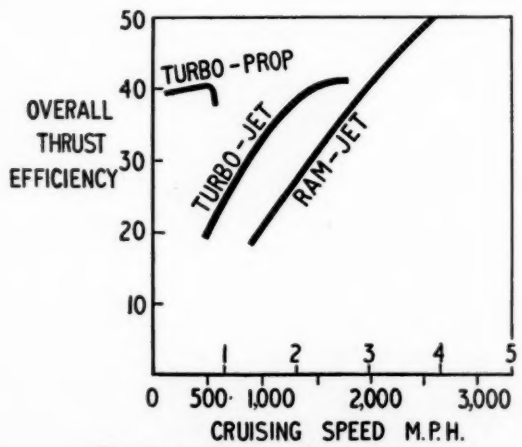


FIGURE 4. The propulsion picture.

is about the limiting Mach number for an air swallowing unit. Above that we must go to some form of rocket propulsion.

It should be noted that use of ram-jets on the cruise denotes some form of "mixed" power plant, since turbo-jet units are still needed for take-off and landing.

3.3. AERODYNAMICS

The aerodynamic picture is essentially a search for shapes giving a good value for the lift/drag ratio on the cruise, combined with tractable take-off and landing characteristics. The flow patterns at supersonic speeds are so different as we sweep through the Mach number range that a variety of aerodynamic themes tend to emerge depending on the chosen cruising speed. At the moment the situation seems to be as follows:—

(*i*) Up to Mach numbers of about 1·2 there is a high chance of minimising wave drag by increasing the sweep-back; carefully shaping the wing body junctions and the wing tips; and judicious twist and camber. Swept wing and "M" wing layouts may postpone catastrophic falling off of L/D, and economical aircraft may be seriously considered which are in effect straightforward extensions of the present subsonic Mach 0·8 swept transport jet themes, but cruising 50 per cent faster.

(*ii*) The Mach number region 1·2 to 1·8 seems unattractive on most counts in that it is difficult to evolve shapes which give a sufficiently high L/D to counter-balance the adverse influence on economy of lowish speed and lowish engine efficiency.

(*iii*) The Mach number region 1·8 to 3·0 is, on the other hand, singularly attractive. Long slender shapes (rather like the schoolboy's paper dart) can be produced with good aerodynamic efficiency on the cruise which, combined with good engine efficiency and the high productivity associated with high speed, can give encouraging cost figures. At the lower end of this Mach number region it should be possible to evolve shapes compatible with reasonable landing performance. As we approach $M=3·0$, this becomes difficult. Choice of cruising speed within this region rests as much on structural and power plant considerations as on aero-dynamics, since kinetic heating difficulties are mounting very rapidly as we go from $M=2·0$ to 3·0, while the ram-jet begins to rear its head at the upper end of this speed bracket.

(*iv*) Once we get beyond Mach numbers of 3·0, we are on much more uncertain ground, in that far fewer research results are available and far less practical flight experience has been gained. In the region Mach 3·0 to 5·0 aspect ratio, already small, should be made steadily smaller, and obtaining shapes suitable for landing without a radically new approach may prove impracticable if high lift/drag ratios are to be preserved. The new approach may comprise the fitting of auxiliary lifting engines which will carry part—or in the extreme the whole—weight of the aeroplane on landing; or alternatively a major "variable geometry" scheme whereby a substantial increase in wing span is generated at low speeds by mechanical means.

(*v*) Another aerodynamic possibility arises once we

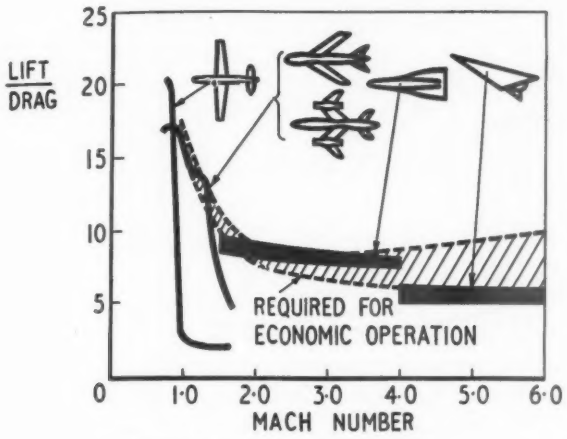


FIGURE 5. The aerodynamic picture.

exceed Mach numbers of 3·0 and approach hypersonic Mach numbers of about 5·0. The aerodynamicist may depart from the "long slender" theme for reducing drag, and exploit "shock interference" layouts in which the body is placed under the wing and its shock wave is made to coincide with the wing leading edge; the wing thereby converts the pressure generated by the body into lift, and attractive values of L/D in relation to flight speed may be possible with a fixed geometry that is not wholly incompatible with landing—since aspect ratios are higher with the "shock interference" layouts than with the "long slender" layouts at extreme Mach numbers. Ram-jets may be tenable at Mach numbers of between 5·0 and 6·0, and the practicability of a plausible and economic aircraft in this region cannot be ruled out, although it is some way off. Still farther off is economic exploitation of higher speed regions well above Mach 5·0 in which aerodynamic heating dominates design to such an extent that aerodynamic efficiency takes second place—shapes are chosen to alleviate heating rather than to keep up L/D.

The foregoing rather cursory aerodynamic excursion is summed up in Fig. 5, where values for L/D obtainable with these various themes are compared with those needed if we are to consider transport designs. The fanning out of the L/D region for economy, at the higher Mach numbers is intended to reflect the increasing uncertainty of structural and power plant parameters as Mach number increases.

3.4 STRUCTURES

The structures man is faced with a variety of new problems when we enter the supersonic regime, many of which become rapidly more acute as cruising height and cruising speed are increased. Some facets of this picture are outlined as follows:—

(*i*) *Size.* In general supersonic transport aircraft are larger and heavier than subsonic machines, since for a given range more fuel must be carried. For example, a Mach 2·0 trans-Atlantic machine carrying 100 passengers will probably weigh about 300,000 lb. on take-off. Undoubtedly the construction of very large aircraft does involve detailed tricks in the design offices, many of which can only be learned by experience. It is therefore essential that any design team dealing with medium or long range supersonic transports should contain a number of people who had previously been associated with the design of really large subsonic machines—be they bombers or transports; supersonic structural expertise on small machines is not enough.

(*ii*) *Shape.* In my view the key to the construction of a really successful supersonic transport will be intimate co-operation between the structures and the aerodynamics teams, and a willingness by the structures specialists to shoulder extra burdens in retaining aerodynamic efficiency without sacrificing in too great a measure structural efficiency. While compromise is of course essential, my impression is that—until kinetic heating problems become acute (say up to $M=2·0$)—the structural problems of a supersonic transport can be gripped with rather more certainty, during the design and construction phases, than the fundamental aerodynamic task of providing the target value for L/D when trimmed for cruising and the desired figure for approach speed on landing. This carries with it the idea that the aerodynamicist should be allowed a little more room for manoeuvre and be shown some tolerance in "playing safe."

One feels instinctively—ignoring for the moment problems associated with severe kinetic heating and the use of novel materials—that the basic structural design of the large but very low aspect shapes suitable for supersonic transports should not be less tractable than that of the very high aspect ratio high subsonic military machines designed for great range (American examples spring immediately to mind), with their obviously extreme aeroelastic problems and their changing aerodynamic characteristics as the speed of sound is neared; indeed, it may be more straightforward. Possibly a major

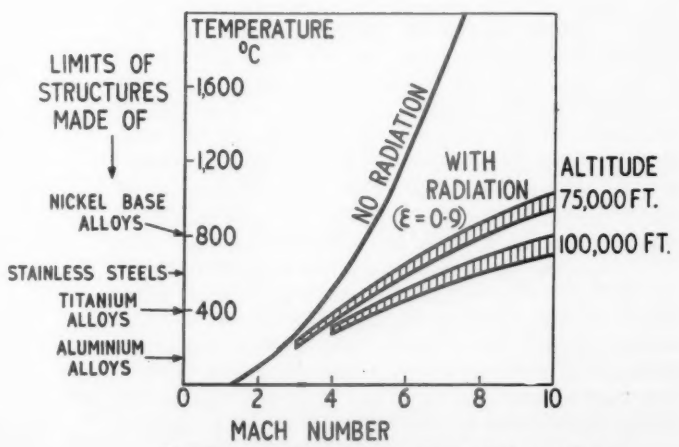


FIGURE 6. Kinetic heating. The materials picture.

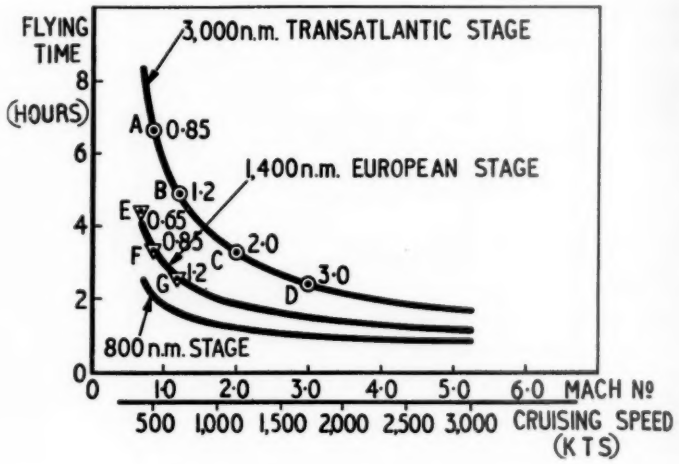


FIGURE 7. Flying time for various speeds and stage lengths.

structural problem with long slender shapes will be the full understanding of how to provide adequate longitudinal stiffness without incurring unnecessary weight penalties; another factor which will bulk large in the designers' thoughts is ensuring complete integrity of the large pressure cabin; integrity essential at heights of the order of 60,000 ft.

(*iii*) *Kinetic Heating.* Once we exceed Mach numbers of about 2·0, kinetic heating is *the* structural problem—as illustrated in the well-worn diagram of Fig. 6. At a Mach number of 2·0 the situation is not over-frightening—the temperature involved is roughly that of boiling water. It gets rapidly worse as Mach numbers exceed 2·0, and between 2·0 and 2·5 the use of conventional light alloy for the main structure becomes doubtful unless steps are taken to insulate it from the heat. Titanium and steel take over—and far less is known about making large aircraft in these materials. In addition the non-metallic picture—and we must have tyres, transparencies, seals, etc.—becomes increasingly more awkward; once we start cruising at speeds round about $M=3\cdot0$ on really large civil machines, a great deal of development will be needed on the materials front before design can proceed with confidence.

While a basic light alloy structure could possibly be stretched beyond $M=2\cdot2$ by extensive use of insulation and possibly going to steel or titanium for relatively small local hot spots, test techniques for fatigue and creep at elevated temperatures will need careful thought; creep tests of complete structures at high temperatures may be particularly time-consuming. Most designers favour a bodily move to steel or titanium once $M=2\cdot2$ is exceeded. Some feel that steel might not result in large structure weight penalties, but would lead to a considerable increase in development and fabrication costs. When allowance is made for cooling equipment, however, some estimate a penalty in extra structure weight amounting to two and a half per cent of the all-up weight in going from $M=2\cdot0$ to $M=3\cdot0$.

The broad picture is that on the propulsion side increased speed is attractive up to Mach 3·0 on general efficiency grounds, and some engine people are not overworried about the internal temperatures involved—theirs is a hot art and they have much experience of special engine materials; on the aerodynamic side again, on general efficiency grounds it is attractive to drift up to $M=3\cdot0$, although compromising on landing performance and on intake geometry becomes increasingly difficult; on the structural and airframe material side, however, kinetic heating does really pose pretty formidable problems of airframe and of systems design as speed is increased beyond $M=2\cdot0$. The structures man would undoubtedly be far happier if he could work somewhere near 2·0 rather than at about $M=3\cdot0$ or above.

3.5. ECONOMICS AND OPERATION

Having dipped briefly into the propulsion, aerodynamics, and structural fields, let us consider what economic pattern emerges when these and other technical factors become welded together by the aircraft designer. A few diagrams will suffice to illustrate the position.

(*i*) *Journey time.* In Fig. 7 are plotted flying times for various stage lengths (London/New York, 1,400, and 800 nautical miles) against cruising speed; allowance has been made for block speed being less than cruising owing to the take-off and landing processes.

This is a simple but most important picture, and one sometimes undervalued in the welter of technical detail surrounding supersonic transports. Apart from the fare he pays, time is what matters most to the passenger.

The big gains of time, as is obvious, are on the trans-Atlantic stage length. However, even here, most of the advantage of supersonic speed has been mopped up by the time we cruise at $M=2\cdot0$ (we have reduced journey time from the 7 hrs. of the subsonic jets to about 3 hrs.).

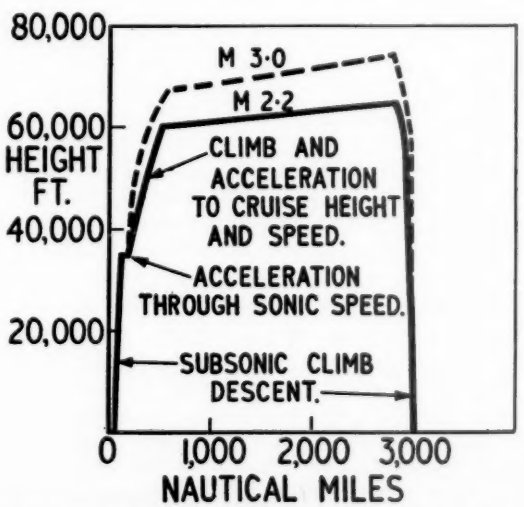


FIGURE 8. Illustrative flight pattern for $M=2\cdot2$ and $M=3\cdot0$ aircraft.

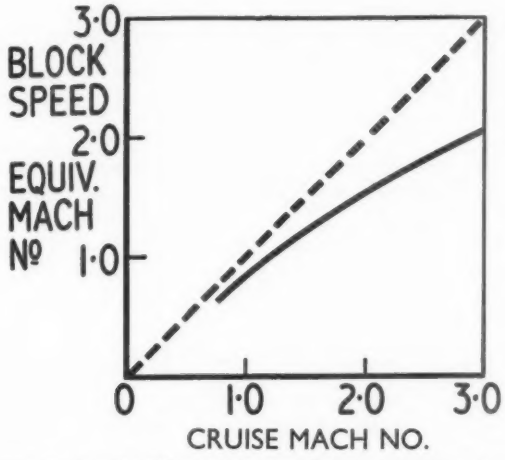


FIGURE 9. London-New York. Block speed compared with cruise speed.

This is a saving of 4 hours and is obviously highly saleable. Cruising at Mach 3·0 instead of at Mach 2·0 only saves a further three quarters of an hour. Thus by the time we reach $M=2{\cdot}0$ the dramatic jump will have been taken. It can be argued that any further increase in speed must rest, not so much on time saving to the passenger, as on a genuine cheapening of costs by going faster. Some, basing their views on subsonic experience, will put in a plea that the competitive virtue of speed margins—in terms of passenger appeal—should not be under-rated.

The medium range curve (1,400 nautical miles) illustrates that on such stage lengths the case for extreme speeds—in terms of time saving—is not strong. A useful saving in time can however be achieved by increasing present day cruising speeds by about 50 per cent—to $M=1{\cdot}2$. For the short range case (800 nautical miles stage length) the virtues of very high speed are the weakest of all, and for such aircraft any drive to exceed sonic cruising speeds must be far less pronounced than for the longer stage lengths.

As a matter of interest, representative flight patterns for London/New York aircraft cruising at $M=2{\cdot}2$ and

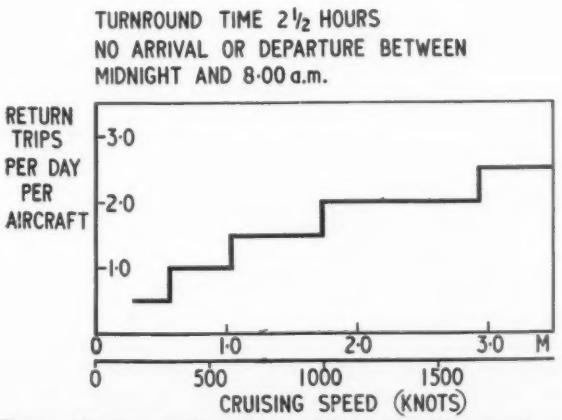


FIGURE 10. London-New York. Effect of cruising speed on number of return trips per day.

TABLE I
NUMBER OF AIRCRAFT TO GIVE 12 ROUND TRIPS PER DAY
LONDON-NEW YORK

Cruising Speed M	0·6 to 1·0	1·0 to 1·7	1·7 to 2·9	Above 2·9
Size of Fleet (No Reserves)	12	8	6	5

$M=3{\cdot}0$ are given in Fig. 8, while block speed is compared with cruising speed in Fig. 9. It will be seen that the "block Mach number" of the $M=3{\cdot}0$ aircraft is just over 2·0; that of the 2·2 aircraft about 1·7.

(*ii*) *Size of fleet.* It is undesirable for timetables to vary from day to day. People do not like arriving or leaving between midnight and 8·00 a.m. There is a time difference between London and New York. The number of round trips per day must be a multiple of 0·5. Adequate turn round time must be allowed for.

All these things make it impossible to evolve any smooth curve to illustrate the influence of aircraft speed on the number of aircraft needed to do a given job. One proceeds in a series of steps. For example, on the London/New York run the number of round trips per day for a single aircraft is illustrated in Fig. 10. The position of the steps is of some significance; in the example chosen, once a Mach number on the cruise of 1·7 is reached the number of return trips per day is two (as compared with one for the subsonic jets). Further increase in speed does not affect the situation until a Mach number of 2·9 is achieved; for this and greater speeds two and a half round trips per day are possible. These figures can be interpreted in terms of the size of fleet to give, say, a dozen round trips per day. These are shown in Table I.

In addition to these bare numbers, additional aircraft would be needed as spares in reserve. It is, however, clear that—if the subsonic and supersonic machines each carry about the same numbers of passengers—once we get beyond a Mach number of 1·7 the total fleet of aircraft needed will be roughly halved for a given work load. It is also clear that there will be every inducement to cut down the number of aircraft in reserve and to minimise turn-round time.

(*iii*) *Traffic potential.* A wide variety of estimates have been made on the potential world market for medium and long range supersonic aircraft. These depend critically on the assumptions made for the growth of world traffic and on the success with which supersonic transports will replace subsonic machines. I would prefer not to place before you dubious curves of average opinion, since the spread is so great as you go from 1970 to 1980. Discussion would be welcome. On one point there is reasonable agreement—that the trans-Atlantic route must bulk largely in any thinking on market potential since the prize here is so great.

As an indication of the order of things, however, estimates for the number of medium and long range 100 passenger supersonic aircraft which could be absorbed on the world routes in the first half of the 1970s range from 150 to 500.

(*iv*) *Costs.* "Non-dimensional" arguments about the influence of technical parameters on costs—deciding

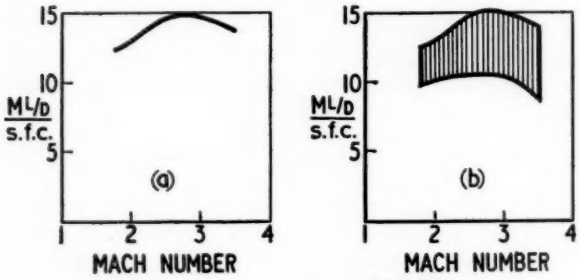


FIGURE 11 (*a*) and (*b*). $\frac{M(L/D)}{\text{s.f.c.}}$.
One estimate and various estimates.

what themes are more expensive than others, what are less, optimising, and so on—can be conducted without too much passion. Supersonic aircraft literature is full of curves illustrating the influence of speed on L/D, engine efficiency, structure weight percentage, and so on, and on combinations of these things. Favourite parameters are:

$$\frac{M}{\text{s.f.c.}} \cdot \frac{L}{D}$$

(where s.f.c. is specific fuel consumption) and: W_0/W_1 (the ratio of fuelled weight to empty weight) since range is proportional to,

$$\frac{M}{\text{s.f.c.}} \cdot \frac{L}{D} \log_e\left(\frac{W_0}{W_1}\right).$$

Typical of the sort of curves published are those in Fig. 11(*a*). On the weight breakdown story, purely illustrative values are given in Fig. 11(*c*). A point to note here is the well known one that, as compared with the more familiar subsonic pattern, on supersonic machines fuel bulks larger and payload less. As for the other parameters, these weight breakdowns become more uncertain at the higher speeds.

It is possible to be misled if parametric curves of this sort, sweeping over a very wide range of M, are taken too seriously and dogmatic deductions claimed about the "best" regions of flight. They are useful guides—no more—to the selections of likely areas for detailed study. Points to be made are:—

(*a*) As cruising Mach number increases, particularly beyond about $M=2{\cdot}0$, much greater uncertainty exists on achievable values for the main parameters. Thin lines, waving up and down as M varies, are more aptly replaced by thick lines getting thicker at the higher speeds. To be possibly a little extreme, Fig. 11(*b*) is a more realistic picture than Fig. 11(*a*).

(*b*) All the main parameters can, in the author's experience, give difficulty: L/D on the cruise; the efficiency of the engine/intake combination; and structure weight percentages.

In the case of L/D, the value must bear some relation to a *trimmed* configuration—not an idealistic bare model; and it must relate to a shape which meets sensible landing requirements. It makes a big difference if approach speed is allowed to be, say, 160 knots rather than being held to 140 knots. Engine characteristics can cause

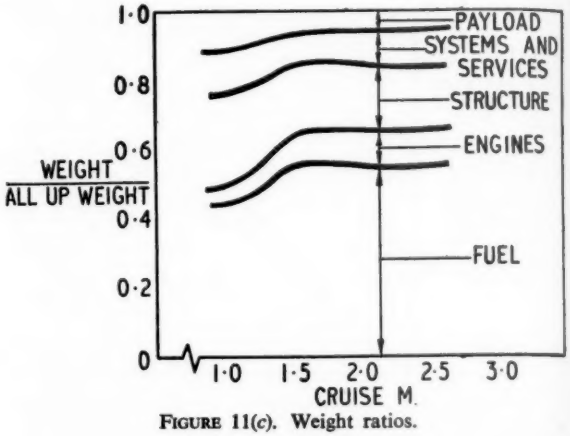


FIGURE 11(*c*). Weight ratios.

confusion. Allowable temperatures—affecting propulsion efficiency; nacelle drag and intake efficiency; allowance for auxiliary power take-off; effect of noise criteria—all of these can be varied and can have considerable influence on the form of the curves. Structure weight estimates, particularly for large steel aircraft, subject to high heating rates and requiring much insulation and refrigeration, can differ widely when based on generalised data. The moral is that fairly detailed design studies of particular aircraft, with realistic boundary conditions, are essential before any confidence can be placed in cost estimates.

Building up from these technical parameters to figures for direct operating costs is a somewhat tortuous business. W. G. A. Port of the R.A.E. has evolved a formula based on current British practice which illustrates the build-up of the direct operating costs C per unit of payload, per mile carried. It is:

$$C = a\frac{fW_F}{SW_P} + \left(\frac{bAW_A + cBW_E}{SNW_P}\right) + \frac{dW_A + eBW_E}{V_B W_P}$$

where a, b, c, d, and e are empirical constants

and

f fuel cost per gallon
S stage length
A initial cost of airframe in £ per pound weight
B initial cost of engines in £ per pound weight
N total number of journeys over the particular route that can be provided by one aircraft in a year
V_B average block speed over the given route
W_F fuel load (lb.)
W_A equipped airframe weight (lb.)
W_E power plant weight (lb.)
W_P payload (lb.)

A formula of this sort is useful in that by assigning firm values to certain parameters, the interaction of other quantities of interest can be studied. For example, quite early in British examination of supersonic transports, R. G. Thorne used this approach to bring out the interaction of structure weight ratio W_s/W_0 and L/D on London/New York aircraft designed to cruise at Mach

numbers from 0·85 to 2·6; in turn holding the direct operating costs to 12 and 24 pence per short ton statute mile.

The type of picture evolved is given in Fig. 12. Grids of this type give useful birdseye impressions of the scene—for example the one chosen illustrates well how marked reductions in values for L/D can be accepted at supersonic speeds, and brings out the greater design sensitivity of the faster aircraft.

It can be seen from the formula that the direct operating costs contain a term involving the initial cost of airframe and engines, and this in turn depends on the numbers built—the larger the number the smaller the proportion of the initial development costs does each aeroplane have to carry, while man hours per aircraft can also be improved as experience and practice accumulates. It is as well to bring this firmly out into the open. Figs. 13 and 14 are taken from some recent British studies of $M=2·2$ and $M=3·0$ aircraft carrying about 100 passengers on the London/New York run. In Fig. 13 the cost per aircraft (taking the cost of a $M=2·2$ machine built in quantity as our unit) is plotted against number built. For numbers over 20 the $M=3·0$ aircraft costs about 70 per cent more than the $M=2·2$ machine; while in the case of the $M=2·2$ aeroplane increasing the number built from 20 to 40 reduces the cost per aircraft by about 30 per cent.

The reaction of all this on direct operating costs is shown in Fig. 14. It can be seen that—if development costs are included in the cost of the aircraft—some 20 or 30 machines must be built before development costs cease to have a profound influence on the picture. In the example chosen, again taken from recent British studies, by the time 30 $M=2·2$ aircraft have been built the direct operating costs are comparable with existing subsonic jets, even when development costs are being recovered fully. The Mach 3·0 aeroplane does not show up so favourably. Even if development charges are ignored, the direct operating costs do not seem to get down to the subsonic jet figure. The moral of Figs. 13 and 14 is that,

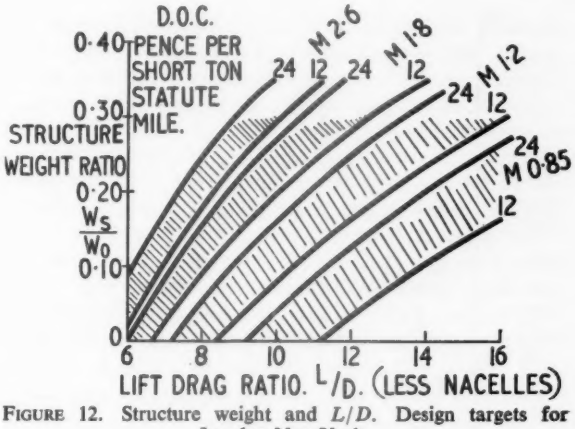


FIGURE 12. Structure weight and L/D. Design targets for London-New York.

when confronted by curves illustrating the influence of Mach number on direct operating costs, the technical man should not only ask the obvious questions about what assumptions have been made about engines, aerodynamics and structure weights; he should also probe the development cost story and expose the assumptions made about numbers of aircraft built.

The final factor in the costs picture is that direct operating costs only account for about half of the total operating costs. It is suspected that some of the submerged elephant might be influenced by the factors affecting direct operating costs; but it is notoriously large and difficult to move. Fig. 15 illustrates the final situation—total operating costs plotted against Mach number from $M=0·6$ to $M=3·0$. The wide range of uncertainty as $M=3·0$ is approached is intended to illustrate doubts about the cruise/landing compromise, aircraft size, and the influence of severe heating on aircraft structural efficiency. As a matter of interest, results of recent British design studies at $M=2·2$ and $M=3·0$—done some time after the bounds on Fig. 15 were evolved—are included.

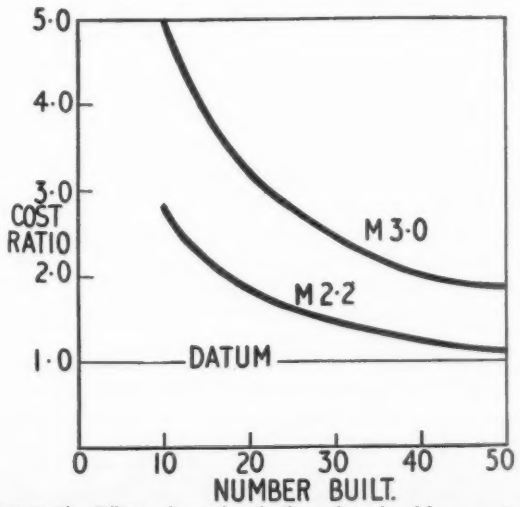


FIGURE 13. Effect of number built and cruise M on cost per aircraft.

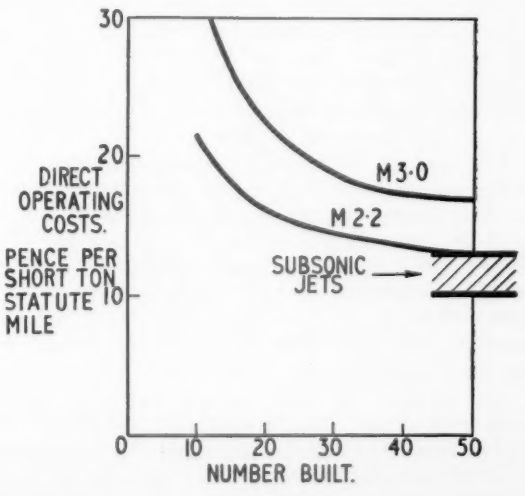


FIGURE 14. Direct operating costs.

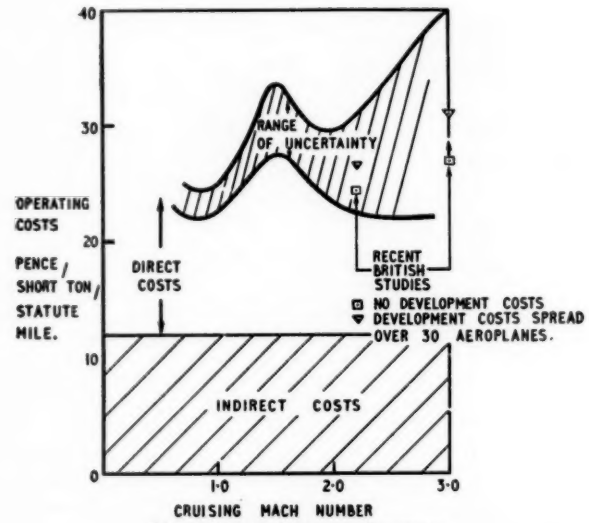


FIGURE 15. Total operating costs.

The lessons from Fig. 15 seem to be that, while the region of cruising speed from $M=1\cdot2$ to $1\cdot8$ does not look promising—since on optimistic or pessimistic assumptions you are fighting a marked bump in the costs curve—anything up to about $1\cdot2$ or above $1\cdot8$ is not ruled out from the costs angle; that overall running costs for supersonic aircraft may be brought to a comparable figure to those achieved on present subsonic jets; and that, once $M=2\cdot0$ is exceeded, difficulties and uncertainties mount rapidly.

3.6. LONDON/NEW YORK. CHOICE OF SPEED AND SIZE

When supersonic long range transports were first mooted some years ago many of us were attracted to stretching the economical "swept-wing" aircraft as far as we could into the sonic region. Research work over recent years has shown this to be a feasible concept aerodynamically up to about $M=1\cdot2$, and the sort of aircraft illustrated in Fig. 16 can be a competitive passenger carrier over medium and long ranges. A study of the journey time curves of Fig. 7 indicate that, while this theme is most attractive for stage lengths of about 1,400 nautical miles—and should indeed come naturally—for stage lengths as long as London/New York there is every inducement to go faster.

Economical "swept-wing" aircraft are difficult to evolve beyond $M=1\cdot2$. The next aerodynamic theme—the "long slender" shape—begins to come into its own at about $M=1\cdot8$. Originally some of us felt that swept wings (or the M wing variants) at $M=1\cdot2$ might be serious competitors of the "slender wing" $M=1\cdot8$ aircraft for the London/New York run. However, research work on the "slender wing" theme has suggested that the overall problems of "swept" and "slender" winged aircraft are quite comparable—provided the aspect ratio of the "slender wing" is not allowed to fall too low, and that kinetic heating problems are minimised so as to allow the use of conventional light alloy construction and to reduce the problems of refrigeration and insulation. These conditions are fulfilled for "slender"

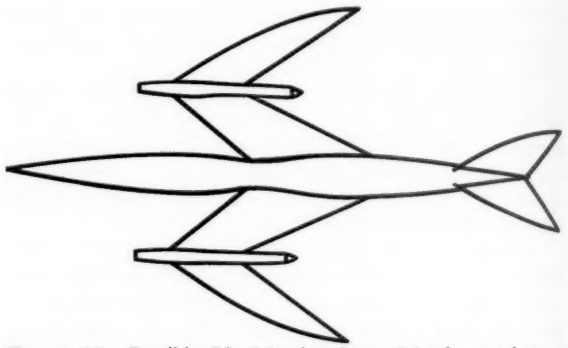


FIGURE 16. Possible $M=1\cdot2$ plan form (M wing variant of swept-wing theme).

aircraft flying in the $M=1\cdot8/2\cdot2$ speed bracket—the sort of machine illustrated in Fig. 17. In the circumstances, since the direct operating costs of both these aircraft show promise of being competitive with the subsonic jets, it seems that the slower $M=1\cdot2$ aeroplane cannot be considered a runner on the trans-Atlantic route.

There will be every inducement to make this light alloy "slender" aeroplane operate nearer $2\cdot2$ than $1\cdot8$; indeed some people talk of $2\cdot4$. However, the whole essence of such a design is to face the new aerodynamic problems boldly while giving the structural and engine interests the minimum difficulty. Operating light alloy right on the edge of its thermal characteristics will obviously be unattractive in terms of uncertainty and length of development time. It therefore seems a reasonable guess that cruising speed will settle in the $M=1\cdot8$ to $2\cdot2$ bracket.

Once new materials of airframe construction—steel and titanium—are decided upon there will be little point in increasing speed marginally over $2\cdot2$; especially since the curves of Fig. 7 and 10 indicate forcibly that extra speed is bringing in diminishing returns time-wise and that $M=2\cdot9$ has to be exceeded to get in one extra crossing per day. It is likely that a Mach number of about $3\cdot0$ will be aimed at, and that the target will be set slightly higher or lower depending on the resources at a designer's disposal, the time scale he is aiming at, and—even with steel for the main structure—the seriousness with which he views the non-metallic materials picture.

The whole of the $M=1\cdot2/M=2\cdot0/M=3\cdot0$ controversy can be neatly illuminated by a single diagram—Fig. 18.

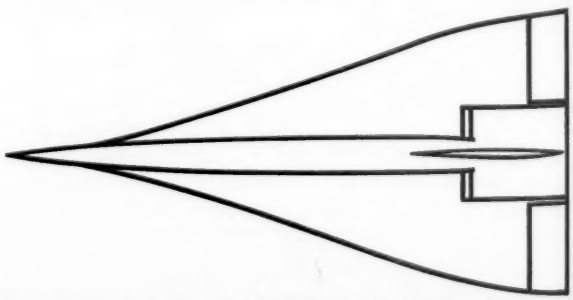


FIGURE 17. Possible $M=2\cdot0$ plan form (slender wing).

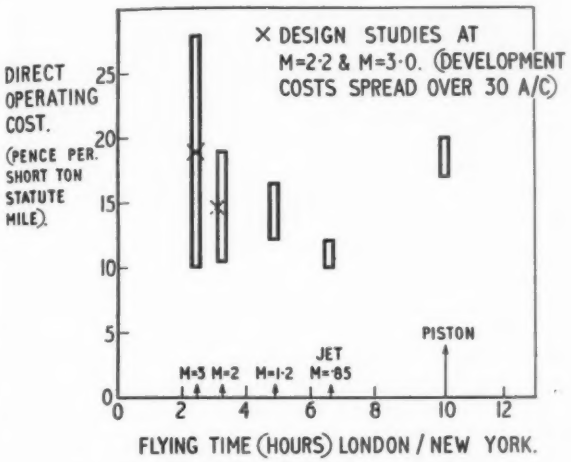


FIGURE 18. $M=3{\cdot}0/M=2{\cdot}0/M=1{\cdot}2$ comparison.

Aircraft size hangs on passenger load. Present studies indicate that, for a given route, the subsonic feature of diminishing direct operating costs with aircraft size still holds good for these supersonic machines—certainly up to payloads of about 150 passengers. World route studies over a variety of stage lengths for the $M=3{\cdot}0$ machine—allowing for its extra productivity and for diminished traffic on the less popular legs—suggest however that on a mixed route pattern 50/100 passengers might be a better aim. The development problems of the faster aircraft are so formidable that there may indeed be every inducement to make it small. However, for a Mach 2·0 machine aimed essentially at the London/New York run—but with flexibility for shorter "Empire" stage lengths—a payload of about 100 passengers might be a good compromise; all-up weight at take-off would then be roughly 300,000 lb.

3.7. NOISE

Supersonic aeroplanes will be noisy—it is no use pretending that they will be quiet. Exaggerated fears have been expressed, however, and the situation is by no means desperate.

Sonic bangs are the most dramatic of people's fears. On all designs considered it is assumed that an altitude of at least 35,000 ft. will be attained, after a subsonic climb, before supersonic speed is reached. The mechanism of the bang is nowadays fairly well understood. Provided that transition to or from supersonic speed is confined to heights above 35,000 ft., it is likely that little nuisance will be caused. There can be some flexibility in the height at which sonic speed is exceeded and the distance from the airport at which transition occurs; on many likely legs it can be over the sea.

The control of internal cabin noise is also likely to be quite tractable. So is the effect of the jet noise field on structural fatigue—in most likely designs the jet pipe exits are aft of any structure and are well placed to minimise such structural interactions.

The real problem is that of external noise during take-off and climb away. The latter can be alleviated by climbing at a steeper flight path angle than is now customary; or by throttling back soon after take-off. Both these are practicable owing to the high power/weight ratio of supersonic machines. However, much attention must be given to noise during the evolution of the power plant and the design of the airframe/engine combination; some themes have been seriously suggested in the past (*e.g.* use of re-heat for take-off) which are singularly unattractive from the noise angle. All that can be said at the moment is that there is every hope, provided noise is taken seriously from the start of a design, that disturbance during take-off and climb can be kept down to about the level at which present subsonic jets are operating; but that it will be extremely difficult to make supersonic machines quieter than present-day transports.

3.8. TRAFFIC CONTROL

Many difficulties have been visualised in adapting our air traffic control apparatus and procedures to deal with supersonic transport aircraft. Some of these fears are based on the high cruising speed; others on a belief that when nearing an airfield a supersonic machine will be a quite abnormally fast and unmanoeuvrable contrivance.

The important thing here is for the designers of supersonic aircraft and air traffic control organisations to get together at a really early stage, since many fears are unfounded. High cruising speed from many angles gives more certainty—wind errors for example are markedly lessened; while the navigational problems on the cruise are not technically at all formidable. A typical Mach 2·0 trans-Atlantic aeroplane, once committed to the descent from about 60,000 ft., will start losing height about 200 miles from the airport. It will reach 35,000 ft. 120 miles from the airport, and thereafter will fly at about 200 knots E.A.S.; during this time it will have similar manoeuvrability, control, and turning performance to any subsonic machine flying at 200 knots; finally, on the approach, it will probably come in not much faster than 140 knots. If diverted at this stage it will have enough fuel to climb away, cruise subsonic, and land at an alternate 200 miles away. This does not sound particularly terrifying. The biggest pressure on the airfield controlling people, from the designers, will undoubtedly be to press on with the installation of completely reliable blind landing aids so that fuel reserves can be cut down to a minimum.

4. Discussion and Conclusions

Trying to take off a national hat, and thereby divorcing myself from the intricate and quite delicate problem of what in detail any particular country should do in the best interests of its own local aeronautical scene and its own internal economy, it is my firm belief that—as always in the past—the world aeronautical picture over the next few decades will evolve largely from severely technical considerations of the possibilities thrown up by the research and development teams; a look at the transport aircraft recently put on the routes or shortly to come in—from America, Russia, France and ourselves—illustrates the strong feed-back between the various independent lines of development and the way

in which the broad themes selected for the big money rest largely on engineering and scientific facts of life; variations of a theme—decisions on just how big a turbo-prop subsonic machine should be, or what airfield performance should be aimed at—bring in the element of competition, commercial judgment stealing a march, and the rest. But the more promising themes themselves should be predictable. I believe that this is so for supersonic aircraft, and the broad pattern emerging from the arguments advanced earlier in this paper is outlined as follows:—

(*i*) Medium range transports, designed for stage lengths of about 1,400 nautical miles, and with a need for flexibility of operation to deal economically with shorter stages, will not rest at a cruising Mach number of 0·8. The advance of our aerodynamic knowledge makes it likely that, by a process of evolution—exploiting and extending existing techniques of using sweepback to suppress wave drag—cruising speeds for these medium range machines will rise to about $M=1{\cdot}2$ (800 m.p.h.).

(*ii*) Over long ranges (trans-Atlantic) the first supersonic aircraft to compete successfully with the large subsonic jets will fly at a Mach number of between 2·0 and 3·0. A Mach number of about 2·0 may prove a natural "fit" for a long range transport, in going fast enough to reap the benefits of really high speed on engine and aerodynamic efficiency, and not so fast as to run bull-headed into kinetic heating problems. Light alloy construction would be used, and engines could be straightforward developments of present day large jet units. Long slender shapes, with subsonic leading edges and supersonic trailing edges, can give sufficiently high L/D while the optimum cruise aspect ratio is large enough for a sensible compromise to be visualised between cruising efficiency and reasonable approach speed.

(*iii*) As against this, long slender shapes can take you aerodynamically as far as $M=3{\cdot}0$, although the landing compromise gets increasingly awkward as design speed is increased. Changing from light alloy to steel will allow the kinetic heating problems on the main structure to be surmounted, and the final choice of Mach number in the vicinity of 3·0—once light alloy is abandoned—may be determined by the non-metallic story. These difficulties would be faced in order to cut only about a further three quarters of an hour off the trans-Atlantic time as compared with the $M=2{\cdot}0$ machine, and would result in more uncertain direct operating costs and greater initial costs; but passenger appeal may be high. At the moment, what might loosely be termed the $M=2{\cdot}0$ and $M=3{\cdot}0$ themes must both be considered as runners. In this paper I have attempted to give ammunition which might assist debate.

(*iv*) Once we start considering the next step—cruising at speeds between Mach 4·0 and Mach 5·0—the whole outlook is more misty. Speed *per se* is giving diminishing returns in a world of finite size, and one begins thinking in terms of faith rather than hard-headed engineering possibilities. My own view is that eventually long range commercial machines may appear on the routes at Mach numbers of between 4·0 and 5·0, using "shock interference" aerodynamics and ram-jet propulsion. It is too early yet to predict whether they will displace the Mach 2·0 and the Mach 3·0 machines. Even more doubtful is the place in commercial aviation for hypersonic vehicles with semi-ballistic trajectories—as economic passenger carriers, few people at the moment would rate this theme as in the field at all, but as knowledge grows this opinion may be modified, particularly if traffic growth justifies special aircraft for extreme ranges well beyond trans-Atlantic. Research designed to throw light on the Mach 3·0 to Mach 10·0 region, in terms of economic flight, is obviously fully justified.

(*v*) We may see—particularly over the higher Mach number brackets—variable geometry or vertical take-off variants coming into their own. Development may depend on a use being found for smaller military aircraft incorporating these features in advance of their adoption on large trans-Atlantic range machines.

Whatever the precise pattern of the supersonic picture which will emerge for medium and long stage lengths, one thing is certain. World aviation is entering a tremendously stimulating phase which will test all concerned, scientists, engineers, operators—and accountants—to the limit. Out of this will come safe, convenient and economic long distance supersonic travel on a scale we still do not appreciate. I very much hope that we in this country play our full part in the process.

DISCUSSION

Mr. Masefield: They had heard a brilliant survey of the supersonic transport field. He thought that it was the first time in a transport discussion that a Mach number of 10 had been on the board, but Mr. Morgan had suggested that he was thinking ahead of that for a lecture later on. The only thing that had not been discussed were some aspects of the human factor, but that also might be a later lecture.

He would ask Sir George Edwards, of what he thought might now be said was the " British Aircraft Corporation," to open the Discussion.

Sir George Edwards (Managing Director, Vickers-Armstrongs (Aircraft) Ltd., *Fellow*): It was a very sensible lecture and knowing the Lecturer, that was what they expected. Even if Mr. Morgan did think the right thing to do was a Mach 2·0 aeroplane and not a steel one, he thought he had refrained from saying so very delicately.

The old ones in the business had a few curves, as well as those that Mr. Morgan had shown. One of these should be an attempt to extrapolate what their retiring age was going to be. As a result, one could be left with an agonising decision as to whether to rush the young wild-eyed citizens to go and do something really nuts (knowing that one would be out hoeing potatoes by the time they had found out it would not work) or whether one was going to be unlucky and left in one's declining years with a pretty high

pounds-worth of machinery wrapped round one's neck. In the latter case, they knew perfectly well that the really hard thing (and of course this was omitted from the supersonic experience the lecturer outlined that they had) was getting the lurid thing down on the ground again. Power-on stalls on M wings, he reckoned, were really something that should be worth having a go at.

Being serious, he would think that they in the aviation business, collectively (and he did not mean the hammer-and-chisel experts, but the airlines, the governments, the military, and the rest of them) were never faced with such a responsibility as they had now. Mr. Morgan had said, very rightly, that aeroplanes were always being pressed on to have big jumps. There was always feverish activity in the design teams of the great nations to do better than the chaps next door. One of the net results of this (and the equal enthusiasm on the part of the sales directors in the airlines of the world to get half a yard in front of the Joneses, or the Joneskis) had been a relative absence of stability at any time. Here was an opportunity, he thought, to make the whole situation more unstable and more ruinous than ever before. He thought that the greatest problem of all was to get this one right at the right time. If they did not, then everything was going to be a waste. It was going to be worse than a waste—it was going to do harm. He was old-fashioned enough to think that one of the things that settled what you were going to do, was what you were capable of doing. He did not think you could rush off and do something merely because you thought somebody else was going to do it if you did not. He thought that if you were incapable of doing something, it did not necessarily follow that the Lord was going to make it plain to you the next day how to do that thing. That view, of course, could be taken as a sign of advancing senility.

He had once heard Mr. Morgan and a colleague deliver a paper on control characteristics, and he would like to hear his views on what he thought the control characteristics of a Mach 2 slender delta might be like.

If the British kept within their capabilities they could produce a better aeroplane than anybody else, either the Americans or the Russians. He thought that if they did not keep within their capabilities, they would fall flat on their faces, and nearly ruin themselves in the process. He thought if they tried to do the thing too soon it was going to have the same effect. This was going to be a long and difficult job, and the chaps who were going to do it knew better than anybody just how long and difficult it was going to be. If, in the face of all that, either the Americans or the Russians decided to get cracking on an aeroplane that it was probably outside British experience and ability to do, he hoped that they would be adult and responsible enough not to join in the clamour. He hoped they would not say: "If they are going to do a Mach 3 with all that goes with it, then although we don't think we can do it, we'd better try, or we'll be left out."

He thought that was the test of real substance and responsibility. If, for instance, they said they were prepared to go on and do what they could do, then he had no doubt that they could do it better than anybody else.

Mr. Morgan: The stability and control characteristics of long, slender Mach 2·0 aeroplanes, quite briefly, were jolly good. As compared with some of the curves that they had been used to on subsonic aeroplanes forced to go transonic and slightly supersonic, in which the curves wavered round and tied themselves into knots, one could get extremely attractive curves covering the main stability and control parameters with those long slender shapes. Nothing frightful happened as they went through the speed of sound, and they got very plausible-looking characteristics at low speed. He was not suggesting for a moment that it was all roses; a lot of hard work was necessary, and a lot of hard thinking would have to be done. However, it did look as if shapes at Mach numbers of the order of 2 could be obtained which were quite efficient on the cruise, and which could be made to have reasonable stability and control characteristics at incidence, to the extent that they could wind the incidence up enough to bring the approach speed down to something of the order of 140 knots, which was roughly as good as what went on at the present moment—or indeed slightly better. One of the biggest difficulties on these long slender shapes was not so much fore and aft characteristics, but the lateral characteristics, particularly when one put slide-slip on. Some people were rather fussed about the time-hallowed l_v/n_v story. But even there if one looked at the numerous tricks one could play, it did seem that they could make the characteristics of aircraft of this sort reasonably docile for all the angles of side-slip they were likely to need operationally, both in terms of hitting side gusts or in kicking off drift when landing in a cross wind. So he personally thought that bearing in mind that much good work had already been done on these problems, the stability and control characteristics of this thing—both in the cruise and on the approach—were not a major worry on this aeroplane. As indicated in the lecture, once one started squeezing the aspect ratio in order to cruise well above $M=2{\cdot}0$ things became more difficult.

W. O. W. Challier (Chief Aircraft Project Engineer, Aero Engine Division, Rolls-Royce Ltd., *Fellow*): He represented a firm which was only making accessories in this vast project, although important ones. They were only producing engines. They would say however, that having looked into what was needed, they thought they could make engines both for $M=2{\cdot}2$ and $M=2{\cdot}7$ or 3. He was not talking about $M=1{\cdot}2$, because engines more or less existed for that sort of aircraft, if they were wanted. But for $M=2{\cdot}2$, $2{\cdot}7$ or 3, engines could be made—they thought—and they could be made in a time which would be rougly equivalent to the development time of engines which had been developed in the past. They were likely to be expensive, but the whole job was more expensive.

Until a little time ago they were convinced that they knew exactly what sort of engine was wanted for each speed range, and that was the engine which was the best cruise engine. It was a sensible approach, because after all that was how aircraft were made in the past. He did not think the position was quite so simple now, and he would like to emphasise the noise aspect of this job perhaps even a little more than Mr. Morgan had done. There was no doubt that it was one of the most difficult things to deal with. He thought it was more difficult even than the aerodynamic aspect—the cruise L/D—because one did not quite know what to do. If one had a very hot engine it was a very light engine and was very efficient, and was also probably quite cheap to make, but it was terribly noisy. If you had a by-pass engine with some reheat (and the amount of reheat would vary, depending how fast they went) that engine could also be quite efficient in cruise, probably a little bit less efficient. This engine would be less noisy at take-off, but in both cases it seemed that the most promising approach was the one Mr. Morgan

had mentioned: they must over-engine the aircraft, and that did not seem to depend on the type of engine one was going to use but it was a basic fact. At present it seemed the only chance of keeping noise which was obnoxious to communities, down to tolerable levels.

This was a serious aspect, because they all knew how difficult it was to bear the cost of over-engining aircraft. They knew in the past that the smallest engine was the one wanted. If they had thrust/weight ratios of the order of 0·4 or 0·5, supposing they wanted a vertical take-off, they only increased the noise level by 4 decibels, and that he thought ought also to be considered; perhaps this noise problem ought to be approached in a slightly different way. It might be there were certain combinations of power-plants that would be required to improve take-off to an extent which would bring the noise level down to tolerable levels. It might well be that that was one way in which this problem could be countered, and that it was preferable to an aircraft which was just purely and vulgarly over-engined, which was the obvious solution.

One thing they also felt about the engine side of this job was that this was such a difficult job that it would be wrong, in their opinion, to say that they would just take any engine which could be developed, although it might be a little worse than a new engine, and try and fit it into this aircraft. They felt that this job was so difficult that it warranted the development of the best engine that could be designed, making use of the most recent advances in aerodynamics and materials, otherwise the handicap would be severe, in fact it might be so great that the aircraft became uneconomic purely for this reason.

P. A. Hufton (Royal Aircraft Establishment): He had one comment on the aerodynamic side which had a certain relevance to what Dr. Challier had said. They had managed to get the L/Ds up to the value of X (he would not say what X was, it would be quite impossible to do that) after a great deal of labour, but it had been obvious to him, and he had been emphasising it all the time, that what they really wanted was X plus 1. They were still going out for X plus 1. It was quite clear that, for instance, on the noise, on the landing and take-off speeds, the ability to be able to exchange the L/D drag ratio, that was fuel weight for extra engine weight, or to exchange it for extra wing area or extra aspect ratio, was of the greatest importance. All he could say was they were going to do their best to get the extra L/D. This would, for example, make fitting of extra propulsive engines, suitable only for take-off, a possibility, and they would be able to reduce considerably the take-off noise.

D. M. Jameson (Air Registration Board, *Associate Fellow*): He was grateful for this timely survey of the position. As he thought anyone from the A.R.B. tended to be regarded as the person who put difficulties in the way, he would like to say that at first he personally felt very pessimistic about the possibility of ever making this machine safe, although he tried hard not to show it. However, his feeling was now that he genuinely thought it was quite feasible.

He thought there were one or two provisos; one had to make the effort on safety which was commensurate with the general effort on the problem, and in particular the maximum effort must be made to get flight experience and to analyse it in sufficient quantity before carrying passengers. Whereas before, operations had started with a very few aircraft after only a moderate number of hours had been flown, he felt it would be prudent not to start transport operations on this type of aircraft until the operator had a reasonable number of them; the period between first flight and the delivery of the fleet should be used to gain the maximum possible flight experience on each aircraft as it became available, with adequate effort being given to instrumentation, to prompt analysis of recordings, and to digestion of the total experience so gained, before passenger-carrying started.

Had Mr. Morgan anything to say on atmospheric research? They had been interested in the properties of the atmosphere which were relevant to subsonic aeroplanes, and the rocket enthusiasts were concerned with its properties at a hundred thousand feet, but there seemed to be less interest in the atmosphere as relevant to this aeroplane. There was nothing to suggest that at some altitude there was a deadly hush, with no gusts and no turbulence. Could Mr. Morgan help them here?

He also wished to hear Mr. Morgan's views on the question of cockpit instrumentation to enable the aeroplane to be precisely controlled during take-off. Mention had been made in America recently on the desirability of improved take-off instrumentation, and he imagined the same sort of thing would apply to this aeroplane; in view of the sensitivity of economics to field lengths, he felt that this was something which it was most important they should hear about.

Mr. Morgan: He did not really believe that this aeroplane, in these particular contexts, was going to produce any desperately abnormal problems. Quite a bit of military experience had been gained now in flying at extreme heights, and admittedly they would like to know more about the atmosphere at great heights. But it seemed to him that in order to get well behaved air the higher they went the better. If one could get above the tropopause and above the weather, good. The tropopause admittedly went up quite high in the tropics, but nevertheless there was everything to be said for cruising at really substantial heights, in terms of avoiding misbehaviour of the atmosphere. He was not suggesting they knew all, but he thought in looking at the problem no one had yet pulled out any frightful mine lying around, waiting to blow them up. The problems of operating an aeroplane of this sort, cruising where it ought to cruise, at 60,000 or 70,000 feet, should be more straightforward than the problems of a military aeroplane which for operational reasons had to go really fast, well and truly in the weather, and fly at high speeds low down, through widespread areas of gusts, turbulence, the lot.

On cockpit instrumentation he might have kidded himself, but in their studies of $M=2{\cdot}0$ aeroplanes he had come to the conclusion that it was just going to be another big fast aeroplane. It was not going to be frightening in terms of its demands on the pilot. Much thought would have to go into the cockpit instrumentation, but that had also applied to the present big subsonic jets. He was certain that many of the lessons they learned from the present subsonic jets would be passed straight on to this aeroplane.

One peculiar characteristic of the aeroplane would be that the pilot would run through a rather larger incidence range than he was used to, because the slope of the lift curve was relatively low, and this might initially present designers and pilots with some problems on the best guidance to hit off the right incidence appropriate to flight conditions; and it complicated the provision of adequate view ahead on the approach.

None of these seemed terrible problems as compared with those they had had already in going from the quite slow piston aeroplanes to the big subsonic jets.

Dr. A. E. Russell (Director and Chief Engineer, Bristol Aircraft Ltd. *Fellow*): The Supersonic Transport Aircraft Committee which was formed rather more than three years ago, served as the generating station which had powered most of the investigations which had taken place in this country since, and he was very glad to see that its Chairman still retained his enthusiasm. It was to be hoped he could transmit some of this to the Ministry to which he was now attached.

He agreed with Mr. Morgan that it would be wrong to exaggerate the difficulties in producing a supersonic transport provided that the stagnation temperatures were kept within reasonable limits. On the other hand, he thought it would be impossible to exaggerate the difficulties by going beyond certain limits. An approximate temperature as a point of reference was boiling water—not too precise, because this varied with altitude.

One could split the problem down, as usual, into three parts. Firstly he did not think the aerodynamic problems associated with the slender shape were any more difficult than those which faced them in the development of swept-back wings, particularly those of high aspect ratio. He thought also, on the structural side, there were no problems which were even as difficult as those which had been met before. Certainly the systems were not any more difficult, again with the proviso that the temperature did not greatly exceed that of boiling water.

He thought that to go beyond the point at which an aluminium alloy was suitable for the main structural parts, they should be running quickly into trouble, especially as regards the systems. For example, a hot fuel system was enough to terrify anyone. It was wrong to assume that just because an aeroplane might fly at a Mach number of 3 the journey would seem any faster—in a state of nervous apprehension it would seem interminable.

Another fact was that some of the materials necessary for application at higher speeds were extremely difficult to handle and extremely expensive to buy. For example, the latest quote for titanium was approximately ten times the cost per pound of light alloy, something like £4 10s. 0d. a pound, on the assumption that one must order at least 200 tons of it a year.

There was only one thing that he wanted to qualify in the Lecturer's remarks, and that was that size inevitably paid-off. The Lecturer showed that the cost of the units decreased with increasing numbers; now increasing the size reduced the numbers required; the aircraft might be less flexible and less applicable to other routes around the world. The first cost would rise and the operating costs would inevitably be reflected. He thought Mr. Morgan struck about the right compromise with 100 passengers, or thereabouts. There was no doubt, however, that the growth of traffic on the North Atlantic would justify aircraft with at least 200 seats. It was difficult over the rest of the world to justify more than about 70; a compromise of about 100 did not go too far in either direction.

As regards numbers of aircraft, too, he thought that it was easy to be too pessimistic. A simple analysis revealed the airlines' own estimates of the seats that they expected to sell in 1965; such numbers could be established by the number of seats provided multiplied by the numbers of aircraft either in service, or on order. Those numbers were equivalent to around 200 aircraft specifically on longe-range operations, *i.e.* exceeding 2,000 miles. Quite modest estimates of annual increases of traffic showed that the increased work capacity of the supersonic aircraft just about kept pace with traffic growth and the required fleet size should remain unchanged.

Historically of course, also, it could be shown that all the traffic did not travel by the most glamorous aircraft offered. Normally this was some 60 per cent, or thereabouts, so that he thought it was reasonable to assume that throughout the world there was a market for at least 150 aircraft, approximately 50 of which would be in the British Commonwealth, 50 in the United States and 50 in the rest of the world, excluding the U.S.S.R.

L. F. Nicholson (Director-General, Scientific Research (Air), Ministry of Aviation, *Fellow*): He had a strong personal belief in supersonic transport. They had heard a little about the possible market and had estimates based on extrapolating current rate of growth. He believed himself that some of those might be under-estimates in the sense that he believed supersonic transports would themselves, of their very nature, lead to an expansion in the market for long-range air travel.

The other point he would stress was that in this country they really did have something special to contribute. A great deal of work had been done over the past few years in this country. He thought some of it was unique, and that they had a real technical achievement to exploit. He naturally accepted that the launching of a supersonic transport was a financial, as well as a technical problem, but he did hope that business considerations and the unnatural economics under which air transport had operated in the past would not prevent this country from exploiting its own particular excellence. They needed to get the size of the job into perspective. It was a big job, but he did not think it was a job which, provided they made the right choices, was too large for them to tackle. The timing was important, but he could not help feeling that the right time was the earliest practical time at which to start the job. They would need time: clearly they would run the risk of falling flat on their face if they tried to rush things too fast. That, surely, was an argument for starting, definitely and quickly, to give them the maximum possible time. He did not believe there could be any argument in favour of waiting to see what happened. They had something to exploit, and he hoped they would be able to exploit it.

Mr. Morgan had emphasised the diminishing returns to be gained from increasing cruising speed. He agreed completely with this conclusion at this stage but he thought one of the lessons to be learnt from Mr. Morgan's curve comparing the cruising speed and the block speed was that if they were to go faster on long ranges or on medium ranges, they needed to attack not only cruising speed, but also the lost time in any of these journeys. This lost time, which amounted to 40 minutes or so on the figures shown, was not quite an act of God. He thought that something could be done to cut this lost time. In the long run they might have to look, if they were going to have faster aeroplanes, to trying to design for saving time during this accelerating process and decelerating process. Saving time there was worth tackling and there was enough to be gained in the long run (and he was not talking now of first-generation aeroplanes) without going beyond the natural limits of human acceleration to justify an investigation.

D. G. Brown (de Havilland Aircraft Co. Ltd., *Assoc. Fellow*): On the question of lost time, they must consider the system as a whole and therefore must consider all the other lost times in the process, such as on the ground, in passenger handling and getting to and from the airport. The total time taken at the ends of the journey could be comparable to the trip time for the supersonic transports cruising at speeds greater than $M=2{\cdot}0$. Thus, concurrent with their efforts on the airborne phase of the operation, already outlined by Mr. Nicholson they must concentrate also on the system that backed it up. Although improvements were proposed, *e.g.* the monorail, to improve total journey times with subsonic transport, they were even more necessary to the supersonic transport.

Other speakers had referred to the effect of size, and Mr. Morgan suggested they should go for the largest size they could hope to fill. They must also take into account the effect of size on the development cost and on the first cost of the unit, since as the diagrams showed there was a marked increase in the unit cost with the smaller numbers; therefore if they were going for a large aircraft they might only expect to sell a smaller number of them. So he thought that there was a secondary effect of size, where a larger number of the smaller units might be a much better thing to do than the maximum size. This could also cut down the development period, in that they could have a larger number of flying prototypes and development aircraft for a given capital outlay, and could get more flying hours per annum for that outlay. That was a point to be kept at the back of their minds.

G. H. Lee (Deputy Chief Designer, Handley Page, *Fellow*): He would like to mention a technical possibility which might supply the plus 1 that Mr. Hufton wished to add to the X (which he equated to L/D). What he had in mind was that normally one thought of a supersonic aeroplane as having a great deal of drag associated with it, and it did indeed have rather more than the average subsonic machine. One thought of it having a high wave drag and a high lift dependent drag, and so on. So one perhaps did not naturally think of applying boundary layer control (*e.g.* suction) to obtain drag reduction in such a case. But when one looked at the break-down of drag of a typical slim delta layout it was surprising to find that something like 40 per cent of the total cruising drag was skin friction; and when one realised that it became clear that one could start to do something by tackling that item. At present they did not know much about the application of boundary layer control by suction, or other means, come to that, to reduce drag at supersonic speeds, but it seemed probable that it could be done. If they liked to make quite a modest assumption, that the skin friction drag was reduced by one quarter (*i.e.* to 75 per cent of the unlaminarised value) they would save 10 per cent of the cruising drag. That meant that the lift-drag ratio was increased by 10 per cent—and that was very small compared with the fact that, subsonically, they could pretty well double the lift-drag ratio by suction. So, assuming that they could get this 10 per cent then, since the weight of the cruising fuel was something like 25 per cent or 30 per cent of the all-up weight, it followed that a saving of 10 per cent in the cruising drag should save a quantity of fuel whose weight was approximately 2½ per cent of the all-up weight. If it were further assumed that the weight of suction plant and equipment was offset against the saving of power plant weight (because the cruising drag was less the engine weight should be smaller) it could be argued that this 2½ per cent of the total all-up weight could be added to the payload. These assumptions were simple, in fact rather crude, but he felt that they were fair approximations to what was likely to happen.

In a typical case, the payload would be between six per cent and seven per cent of the all-up weight so the saving of 10 per cent of the fuel could represent an increase in payload of between 30 and 40 per cent; to increase the number of passengers by this amount should result in a considerable reduction in direct operating costs.

The thing to remember was that although the drag saving was fairly small, a long range supersonic aeroplane (he was referring to the Trans-Atlantic type of range) was operating so near what had been called the ultimate of asymptotic range that even a small drag saving could make a significant difference to operating costs. (In using the phrase "asymptotic range" he was referring to the common way of plotting the all-up weight necessary to carry a given payload against the range in question; this curve showed a rapid increase in the necessary all-up weight as a certain limiting range was approached). Therefore it was clear that quite small drag improvements were worthwhile for this type of aeroplane.

The question of timing had been raised by a previous speaker; it was clear that to incorporate boundary layer control into a design of a supersonic aeroplane would delay the completion of the design and manufacture of the aircraft, therefore it was necessary to consider two different policies; one was to proceed immediately and design a supersonic aeroplane using existing knowledge and obtaining, as a result, a reasonable aircraft, but one that was probably more expensive to operate than subsonic types which would then be competitive with it. The other policy was to delay the completion date by a year or two so that boundary layer control could be incorporated with the result that they might anticipate producing a very good supersonic aeroplane, which could well have direct operating costs competitive with other types that would then be existing. The answer as to which policy should be followed clearly involved many matters other than those pertaining to aircraft design, in particular, the needs of the Airline Corporations and their re-equipment programmes must obviously greatly influence the decision; there was also the question of foreign competition.

Mr. Morgan: He was sympathetic to the idea of drag reduction by laminar boundary layers because undoubtedly the supersonic aeroplane was a bit more touchy than the subsonic one, and there was every inducement to seize the whole of the technical "bright ideas" bag and pull out all the tricks they could because they were scratching on these fine margins. He must say, however, that speaking personally, his instinct would be to go *initially* for the simplest and easiest aeroplane which really would do a good job; and then on later aircraft to start playing the tricks. If, for example, the kinetic heating problems were ducked they could reach a stage in which they built a complex, big and pretty fast aeroplane, but had not got a *desperately* difficult task in front of them. He felt they would learn a great deal in facing this task and doing it really well; then subsequently improve and go on improving this new breed. He was quite certain that while they got all excited about what would come first and who would do it first and so on, the curves that they had seen showed quite clearly that for the next 20, 30, 40, 50 years supersonic travel was going to be with them in an increasingly big way. These supersonic transports

would not be with them for prestige; they were going to do a good, honest and economir job. So they were really entering a vast field, and provided they got into the field sensibly, so that they were learning the trade in it, then there would undoubtedly be many future generations of supersonic aeroplanes on which they could get cleverer and cleverer; and time went by awfully quickly.

J. C. Floyd (Advanced Projects Group, Hawker Siddeley Aviation Ltd., *Fellow*): This was a monumental lecture. It posed a problem, in its very excellence, which Sir George Edwards had not mentioned, and that was that the two great consortia who had been given the job of doing the Supersonic Transport feasibility study were now in danger of having it cancelled, because the Ministry could get a copy of the paper.

He did not think Mr. Morgan made enough about the low-speed characteristics. The off-cruise conditions of take-off, initial climb, descent, alternates and general subsonic areas, accounted for such a large part of the fuel that the aircraft had to be designed around those areas and this resulted in reasonable landing characteristics. Mr. Morgan mentioned that favourable interference effects came in at something over a Mach number of 4. The B-70, however, was designed for $M=2{\cdot}8$ to 3 and used favourable interference. So there might be a case for favourable interference at lower speeds.

Mr. Morgan: Indeed these off-design cases were important, and he possibly should have stressed them more. But it might be interesting to give an illustrative figure on lift-drag off-design, because he thought the answers there were a bit surprising. If one got these long slender shapes and ran them subsonic—and one had to for part of the flight pattern—one could, without any tricks of increasing the aspect ratio, expect a lift-drag ratio of something of the order of 11 subsonic, as compared with, say, 18 for a properly designed subsonic aeroplane. When one compared the very different shapes of the high aspect ratio subsonic jets and the very low aspect ratio "slender" supersonic aircraft, this really was a surprising and comforting figure.

Mr. Masefield: They had had a fine lecture and an excellent Discussion, although he was sorry that there had been no comments from operators. As Sir George Edwards had said, the big supersonic aircraft issue which faced British aviation today, in whichever direction they went, would influence the whole of their manufacturing set-up during the next few years, because the effort needed would be enormous.

One of the points to be borne in mind in this new régime they contemplated entering was that they were talking of flying passengers at speeds faster than all but one or two military aircraft had achieved. The date at which such an aeroplane might come into service had not been discussed but guesses, he thought, would range from the late sixties to the mid-seventies.

But the issue as to whether or not this country should go into the supersonic transport and, if it did, exactly what kind and when, was the biggest issue facing them in aeronautics at the present time. Mr. Morgan's lecture and the Discussion he was sure would be of material assistance to the decisions that had to be taken. Mr. Hufton, he thought, had given them the clue in his spoken reply by quoting *Hamlet*. He could not help feeling that—"To be, or not to be, that is the question."

Captain A. P. W. Cane (B.O.AC.. *Associate*) *Contributed*: As a practising pilot he found the lecture on the whole, to be encouraging from the viewpoint of one who hoped to be able to fly one of these aeroplanes before retiring from active flying.

He was pleased to note that the lecturer offered hopes of being able to keep approach speeds within reasonable limits and, although aware of the overall performance penalties for so doing, he was a little puzzled by Mr. Morgan's reference to the designer's sacrifices in the past in reducing approach speeds—these having more than doubled during his flying career. In this connection, in answer to a question, Mr. Morgan had said he considered the approach characteristics would be "plausible"; this caused him some concern since he associated this word most readily with "rogue," and "rogue" aeroplanes were far from acceptable.

Apart from the effect of pure speed on approach success in limiting weather conditions, there was also the effect of cockpit coaming cut-off due to the high nose-up attitude of the delta shapes shown in the sketches; this by limiting the available visibility from the cockpit would automatically increase the minimum visibility required for landing, in addition to making the visual approach and landing more difficult to judge. This emphasised the need for a reliable automatic landing system in order to maintain and/or improve on present-day limiting weather conditions.

If he recollected correctly, there was no reference in the lecture to cockpit visibility requirements which, he gathered, might well be a considerable problem in the type of aircraft envisaged. It would seem that, from a pilot's standpoint, view from the cockpit in the subsonic stage of flight should not be inferior to that achieved on the present large subsonic jets. These angles of view, however, appeared not to be necessary at supersonic speeds. He had heard it said that aerodynamic noise on forward viewing transparencies at supersonic speeds might well be unbearable within the cockpit; had the Lecturer views on this?

He was surprised to hear that Mr. Morgan was not anticipating any atmospheric problems at cruise altitudes. This statement took him back some ten years to the beginning of the Comet I era when the cry was "No weather above 35,000 feet." Did they really know enough to say that there could be no problems between 55,000 and 70,000 feet? Past experience seemed to show that each new altitude had produced its own problems with regard to the atmosphere. Certainly they knew that cumulo nimbus went up to 60,000-65,000 feet and there would be a considerable problem in detecting this early enough to take suitable avoiding action at the speeds at which they would be flying. There were also the problems of turbulence and rapid temperature variations; with regard to the former it would appear that it would be necessary to have both cruising and rough air speeds similar owing to the impossibility of anticipating the onset of turbulence and the difficulties of slowing down the aircraft, if this were to be considered necessary.

With regard to the utilisation chart shown, which precluded the use of the aircraft between midnight and 8 a.m. on a proposed Atlantic routing, he had two points to make; firstly the introduction of supersonics on the Atlantic turned the trip from a time aspect into their present concept of a short haul sector and, therefore, the night hours might well be utilised by special night tourist fares which, he was told, were not proving unprofitable. Secondly, it was highly probable that the aircraft would not stop at New York but carry on round the world, in

which case somewhere these night hours were bound to be utilised.

G. A. B. Lord (Deputy Directorate of Control and Navigation (Development) M.O.A., *Associate*) *Contributed*: Air Traffic Control planners and pilots in particular would be reasonably satisfied to hear the Lecturer's suggestion that final approach speeds for supersonic transport aircraft would be of the order of 140 kts., although other experts had suggested they might be as high as 180 kts. for a $M=3$ aircraft. Mr. Morgan also expressed the opinion, if he understood him correctly, that the aircraft's manoeuvrability both in cruising flight and in the approach configuration would be comparable with, and probably no worse than, that of existing large subsonic jets. It would nevertheless be reassuring to be given some evidence that not only could the performance of present large jet transports be equalled but probably improved upon.

As regards cruising flight, it was the acceleration likely to be accepted by passengers, rather than the manoeuvrability of the aircraft, which would be the governing factor in relation to Air Traffic Control and navigation. It was suggested that about $0{\cdot}25g$ normal to the passenger would be acceptable for routine manoeuvres. This represented a lateral acceleration of $0{\cdot}75g$ associated with a bank angle of approximately 37°. On this assumption a $M=3$ aircraft would travel 88 n. miles along track while correcting a 30 n. miles lateral displacement with zero heading error. A gentler manoeuvre employing 14° of bank and a lateral acceleration of $0{\cdot}25g$ would carry the aircraft 168 n. miles along track to correct the same displacement error. The overall aircraft/navigation system must either be capable of nulling such errors before the aircraft entered the terminal control area or, preferably, be of such an accuracy that those errors did not arise.

In the final approach phase of flight, the angle of incidence of these aircraft might be so high that the pilot might not have a direct view of the approach zone and runway. Although various means had been proposed to provide the necessary visual guidance it would be interesting to hear of any other devices, apart from V.T.O.L. techniques, which were likely to solve this particular problem. If visual approaches were considered practicable then it would be well to bear in mind the effect on weather minima of the higher rate of descent associated with the higher approach speed. Using a conventional glidepath angle of 3° it was assumed that a pilot would wish to be in a position to prepare for flare out by the time he was 100 ft. above touchdown height. Before reaching this point he would require about five seconds after breaking cloud to identify and assess his position relative to the runway, five seconds reaction time to decide on and initiate the correct control manoeuvre to bring the aircraft to a position from which a safe landing might be made, and about 10 seconds to effect even a slight S-manoeuvre to correct any azimuth error. In effect, for an approach speed of 140 kts. the rate of descent would be 720 ft./min., the "critical height" would be 340 ft. and the "critical slant range" from touchdown at this height would be 6,555 ft. For an approach speed of 180 kts. these figures would be 940 ft./min., 420 ft., and 8,100 ft. respectively. The approach speed would probably be well below minimum drag speed and it was likely that auto-stabilisation in pitch and auto-speed control would be essential to relieve the human pilot of the almost impossible task of flying the aircraft accurately on instruments, or even visually, as a routine operation during final approach.

These considerations appeared to point to the need for automatic landing facilities to be provided for these aircraft if they were to achieve at least the same order of regularity and safety as existing civil transport aircraft. He believed that the lowest weather minima at present in force at London Airport for Viscounts were 250 ft. critical height and 400 yds. runway visual range. Lowest limits for the Boeing 707 at London were at present 300 ft. and three quarters of a mile (provided that there was an alternate airfield with limits above 600 ft. and two miles). On economic grounds, the supersonic aircraft must operate at least to these limits if a satisfactory utilisation rate were to be achieved, quite apart from the loss of prestige and value to the passenger if a trans-Atlantic flight of two hours ended in Prestwick or Paris instead of London. From the visual exposure times required on final approach, it seemed doubtful whether this aircraft would be able to operate visually in limits much below 400-500 ft. break-off height and one to two miles slant range visibility without accepting a higher accident risk and/or higher rates of missed approaches.

The present civil aircraft accident rate from all causes was about two in 10^6 flying hours and 30 per cent of those occurred during approach and landing. It was earnestly suggested that the present generation of large civil subsonic jet aircraft had not been in service long enough to determine what effect, if any, it would have on the accident rate. From pilots' impressions and information available so far one could not be certain that the margin of safety had not suffered. It would be unfortunate therefore if there were a tendency to regard the existing large subsonic jets as representing an acceptable criterion in matters such as manoeuvrability, performance and handling characteristics simply because the skill of experienced pilots had managed to cope so far without a major catastrophe. Human thresholds had been postulated and passed many times in the short history of aviation and therein lay the danger that some aircraft designers and operators might tend to ignore that somewhere a threshold did exist and many experienced pilots had reason to believe that it might at last have been reached.

Since Hamlet was invoked at this excellent lecture, might he conclude with one of the King's comments?

> "Let's further think of this;
> Weigh what convenience both of time and means
> May fit us to our shape: if this should fail,
> And that our drift look through our bad performance,
> 'Twere better not assay'd: therefore this project
> Should have a back or second, that might hold
> If this should blast in proof."

N. E. Rowe (Joint Managing Director, Blackburn Aircraft Ltd., *Fellow*) *Contributed*: Mr. Morgan had given a graphic presentation of the pros and cons of supersonic air transport. He saw the aeroplane operating at $M=2{\cdot}2$ as "only another big aeroplane," and advised them not to exaggerate the difficulties and be daunted by them. One could, he thought, accept this attitude but it carried certain implications. Surely the big problems of such a project lay in the field of materials and construction. Hence, it might be argued that they should attempt a real technical advance in this field, or otherwise they would only be building another big aeroplane. His view was that they should make this advance by departing from aluminium alloys as the main materials of construction and use others, probably steel for the main structure. This would free them of the major difficulty of working with aluminium alloy at a near-critical condition of elevated temperature with the accompanying effects of creep and fatigue.

In his recollection of the lecture as given, little had been said about the possible use of V.T.O.L. for a supersonic

transport aircraft. It could, he thought, be argued with justice, that while this brought its own problems of stability and control and engineering, it freed the designer from problems associated with normal airfield use. It seemed to him that the ability to move vertically would also greatly ease the problems of Air Traffic Control which might be of over-riding significance in operations. One great advantage in the V.T.O.L. engineering was that a great deal of it could be proved on the ground. Maybe the combination of steel structure and V.T.O.L. installations would be too big a step taken together, but that was the combination which would enable the development to advance smoothly to cruising speeds of say, $M=3{\cdot}5$.

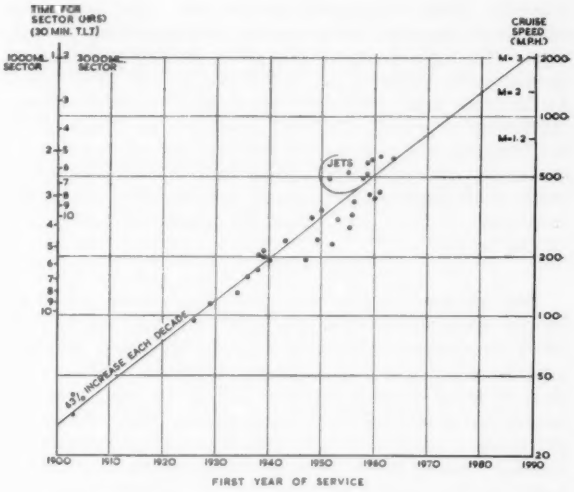
Mr. Morgan had said that one could not be too definite on figures for economy at this stage. Nevertheless, the broad picture presented showed there was no advantage in economy over aircraft that now existed, and this situation was likely to deteriorate as time went by, since there were still a number of improvements and refinements in design, construction and operation which could be made to reduce the cost of subsonic aeroplanes. But in an enterprise of this kind it would be wrong to take economics on its own. It was generally agreed that the challenging conditions met in aeronautics called for constant advances in the science and art which, over the years were fed down to other branches of engineering in the form of new techniques, new and improved materials and constructional processes, and the machine tools which went with them; thus the overall benefit from this constantly renewed challenge was widespread. This reason would be almost sufficient of itself to justify spending money on supersonic air transport, but there was also the question of international prestige, which in these days of acute competition, tended to be of great significance. Ultimately the economics must be comparable with the best subsonic aircraft. This might mean that travellers by supersonic air transport would pay more, since they were saving more time, and time was the main commodity improved air transport had to offer.

He was surprised to see in one of the figures of the lecture, the big difference between direct operating costs at $M=2$ and $M=3$; this large difference did not seem to correlate with the data which had been shown earlier.

R. H. Whitby (Performance and Analysis Manager, B.E.A., *Fellow*) *Contributed*: Mr. Morgan drew attention in his lecture to the tendency of speed and size of civil aircraft to increase with time, and linked this with a corresponding tendency for fares to be reduced. It should be noted that there was no automatic link as between speed and operating cost while, other things being equal, an increase of size did lead to a lowering of operating cost.

Figure A picked out a number of successful civil aircraft from about 1926 and showed the trend of cruising speed and time spent on a 1,000 and 3,000 mile sector against year first in service. It would be seen that each decade there had been an increase of some 60 per cent in cruising speed. During the past 25 years civil aircraft had become social rather than solitary creatures. From time to time newer and faster aircraft had led to difficulties within the Air Traffic Control system and airport surroundings but with time these had been solved.

However, jumps in speed had not been of the magnitude which were now being spoken of. For example, a Mach 3 aircraft in 1975 would represent a more than threefold increase in speed from the highest cruising speeds of 1965. Despite some views expressed to the contrary, it was difficult to imagine that approach speeds would not be considerably higher than at present (for the reasons mentioned by the lecturer). The noise of the supersonic aircraft in the neighbourhood of the airport would be another major problem.



In these circumstances, if such a rapid increase in speed as had been spoken of were envisaged, he would expect that the assimilation of such aircraft would require a completely separate operating system with airports and approaches isolated from those of existing aircraft and with the allocation of the highest altitudes outside terminal areas to supersonic aircraft. In order that the journey time should not be made much longer by banishing the supersonic aircraft from the vicinity of the towns, there would have to be a rapid development in feeding helicopters and other V.T.O.L. aircraft. If such a segregation were impracticable, then to get the faster supersonic aircraft into the subsonic system in a short space of time would demand a major effort (comparable with that being devoted to the aircraft itself) for the development of operational equipment such as navigation aids and computers permitting the precise control of aircraft in three dimensions, and automatic landing. And, what was more, this equipment would probably have to be used by all other aircraft.

J. E. D. Williams (*Assoc. Fellow*) *Contributed*: Having shown that a large part of the operating cost was the amortisation of the capital investment, Mr. Morgan demonstrated the variation of fleet productivity with speed assuming a two and a half hour turn around time. A chart showing variation of productivity with turn around time at high Mach numbers would have shown the startling dependence of economic utilisation at supersonic speeds on efficient ground handling. This was of an order to justify a much more sophisticated and scientific approach to ground handling than had yet been contemplated.

For the purposes of illustration, Mr. Morgan assumed a ground distance of 3,000 nautical miles (London-New York). In the past British manufacturers' of long range air liners had thought in terms of the London-New York route. In his view this was an error. Every operator except B.O.A.C. required more range than London-New York on the North Atlantic route. Furthermore, while the North Atlantic dominated the current market for long range aircraft, this should not be regarded as a fixed geopolitical factor for long range planning purposes.

Contrary to popular predictions, the race to subsonic jets did not eliminate a single airline from the North

Atlantic. Even the smallest bought jets. The long range carriers of the small nations were, in his opinion, there to stay. The supersonic aeroplane they would buy must be economically operable in fleets of two or three units. To provide high utilisation on a regular basis without sacrificing schedule reliability, required a design FOR maintenance, and a design OF maintenance of an order not previously undertaken by any aircraft manufacturer. It might also imply a new set of criteria for mechanical reliability; to "fail safe" must be added "fail rare" and "repair quick."

Mr. Morgan: He was very glad Captain Cane found the lecture encouraging from the pilot's angle. Provided the pilots co-operated intimately with the designers of these supersonic transports in a sober and critical spirit—rather than in terms of playing their part in an unnatural and hazardous enterprise—in his judgment they would be pleasantly surprised at the outcome. The problems of approach speed, pilots' view on the approach, and cockpit noise on the cruise, were tractable. Captain Cane had raised a point of interest in asking whether the pilot could be given adequate knowledge of atmospheric conditions ahead—when he was approaching them cruising three or four times as fast as he was used to. There would, of course, be many problems of that sort, accentuated by the fact that a supersonic aircraft must be somewhat more sensitive than a subsonic machine to routing changes since fuel consumption must be watched with a beady eye. He stuck to his view that, on general grounds, flight at 60,000 ft. or so should present less atmospheric hazards than flight low down. In terms of turbulence and sudden temperature changes, the designer must ensure that the pilot's problems were not made unnecessarily difficult; the pilot must not be forced at any stage to operate unduly close to design limits.

Captain Cane's remarks about utilisation were worth pondering. Any device for increasing the utilisation of these very productive aircraft should have a beneficial effect on costs and hence on fares.

Turning to Mr. Lord's contribution, the purpose of his brief remarks on traffic control in the lecture were to dispel what he regarded as exaggerated fears. On the cruise the turning circle of the aeroplane, with any reasonable "g" limits, must be large. Navigation systems must ensure that large course changes were not needed in a short distance. Once the aeroplane went subsonic, on its last few hundred miles to the airport, it should not, however, be very abnormal. He sympathised with Mr. Lord's view about current standards; in preliminary consideration of these supersonic transports, they had, for instance, had in front of their minds the need to hold approach speeds to reasonable limits and had resisted the temptation of promising more favourable direct operating costs by the device of letting approach speeds rise to unseemly heights.

His old friend Mr. Rowe advocated going straight to steel. As he explained in the lecture, he was endeavouring to provide aluminium for debate in the $M=2{\cdot}0$ versus $M=3{\cdot}0$ controversy. On the light alloy side Mr. Rowe was nervous about operating the material too close to its temperature limits. All aircraft designers were. In his belief, however, they had enough flexibility in choice of speed, between, say, $M=1{\cdot}8$ and $M=2{\cdot}2$ for the light alloy machine, to ensure that one did not bump on the stops but had adequate margins. Mr. Rowe also raised the question of V.T.O.L. for the large supersonic machines. As touched on in the lecture, he had no intention of dismissing V.T.O.L.—for the faster second or third generation supersonic transports. But his personal instinct was to stress *simplicity* for the first generation, and to do without V.T.O.L. for the first venture.

Mr. Rowe mentioned his belief that the supersonic aeroplane was intrinsically less economical than the subsonic machine. Mr. Rowe and he had often argued on this, and he believed that the issue was open. In the work with which he had been associated, they had tried to avoid being wildly optimistic; and they saw promise of comparable direct operating costs for the supersonic aircraft as compared with present day subsonic transports. It could be argued that the direct operating costs of subsonic transport could be lowered considerably by intensive research and development, and that it might be more profitable to concentrate on subsonic work than to, as it were, waste their substance on riotous supersonic living—Mr. Rowe had at times hinted at that. He personally saw no magic wand which, when waved, would slash subsonic costs. There were, however, a number of interesting possibilities, both of engine and airframe design, which—backed by adequate research and development—might well dent them appreciably. However, many of those possibilities were equally applicable to supersonic machines. Once they saw the first generation of supersonic transports launched, he was sure that research must continue into means of making both subsonic and supersonic transports more efficient. Over the longer ranges, however, nothing had shaken him in the view that the large supersonic machines would steadily eat into the overall market and that, as the years went by, they would ultimately dominate it.

Mr. Rowe made a point about consistency in the diagrams—he had checked back and thought that the relative costing as between $M=2{\cdot}0$ and $M=3{\cdot}0$ was consistent throughout. The main point of these relative figures was the increasing uncertainty as severe kinetic heating was faced, bringing with it a wider difference between optimistic and pessimistic assumptions and increased scope for debate.

Mr. Whitby mentioned the problem of mixed traffic patterns and suggested segregation of the supersonic machines from subsonic traffic at the airports. As already argued, he believed that the right approach was for the designer to ensure that the supersonic machine was so well behaved in the vicinity of the aerodrome that a mixed pattern was feasible and acceptable—provided that air traffic control development continued and with a little give and take all round.

Mr. Williams queried the importance of the London-New York distance, and suggested that a slightly longer stage length might be desirable. Most people felt that trans-Atlantic operation was a laudable goal, since traffic potential was so high. Over-insuring on range could be very expensive in terms of aircraft size, and the specification writer would have to face a nice compromise when finalising his demands in terms of stage length, allowances and so on, in the light of market research and guesses on future traffic patterns.

In conclusion, he could not close this written reply to the discussion without reference to the Supersonic Transport Aircraft Committee. The President, in his introduction, mentioned that he was Chairman of this body during the several years of its life. A very representative cross section of those actively engaged in the technical aspects of British aeronautics—from the firms, the establishments, the operators, and so on—took part. It was a privilege to be associated with this venture in co-operative research, and the level of debate and performance made him proud to belong to their aeronautical profession.

SYMPOSIUM ON FLIGHT SAFETY

A Symposium on "Flight Safety" was held by the Society on 11th December 1959 at the Institution of Mechanical Engineers, Birdcage Walk, London S.W.1. The Chair was taken by Mr. Walter Tye, O.B.E., B.Sc., F.R.Ae.S., Chief Technical Officer, Air Registration Board.

Introductory papers were given by Captain J. W. G. James, O.B.E., A.F.R.Ae.S., Flight Operations and Communications Director, British European Airways; Captain E. C. Miles, British Overseas Airways Corporation; Mr. P. G. Tweedie, O.B.E., A.F.R.Ae.S., Chief Inspector of Accidents, Accidents Investigation Branch, Ministry of Aviation; and Mr. R. H. Warde, A.F.R.Ae.S., A.M.I.Mech.E., Bristol Aircraft Ltd.

The Discussion was in three parts—after the second paper, after the fourth paper and in a general form at the end of the Symposium.

The Operator's View

by

Captain J. W. G. JAMES, O.B.E., A.F.R.Ae.S.

(Flight Operations and Communications Director, British European Airways Corporation)

Introduction

It is singularly appropriate that Mr. Walter Tye should be in the Chair today, not only by reason of his membership of the Air Registration Board, that Cerberus which watches so efficiently over so many aspects of safety in the air, but also for a more personal reason. He recently received the " Aviation Week " Award for distinguished service in achieving safer utilisation of aircraft, and I should like to take this semi-public opportunity of adding my congratulations to the many which he has received.

In many of the offices of my airline one finds displayed a small plaque. On it appears, among other words, the legend "Safety is no Accident." Although I am no great believer in the power of an oft-repeated formula to achieve miracles, I do believe that these words hold within them much of my flight safety philosophy.

Definition of Safety

If one is to achieve this desirable state known as "safety" it is as well to know what it is. When attempting to define abstract qualities the dictionary often runs into difficulties, and it does so, in my opinion, when defining "safety." The Oxford English Dictionary suggests "absence of danger or risk." You will at once notice the use of the negative "absence of"—and, with respect to the learned compiler of the O.E.D., I think his definition is inadequate. Can one enjoy in an imperfect world a state of total absence of danger or risk? You cannot; even those situations which appear to be quite harmless can be found to contain some possibility of danger. I conclude therefore that all states of so-called safety must in fact be relative, that is to say, they contain more or less danger or risk than other situations.

If this is so, it follows that all those who work to promote safety, whether in the home, on the roads or in the air, are working in a fluid situation where there are no fixed marks and no final target to be achieved. In case this should appear to be too extreme a view to take, I would qualify it by adding that as we are human we set up our own marks and targets by which we attempt to gauge our progress. Therefore when an operator adopts a certain standard, he is not ignoring some absolute standard which he could if he so desired adopt in its place.

This is important, because there is a tendency in some circles to assert that the operator is aware of the "best," whatever that may be, but for various reasons is content to accept something less than the best. Unfortunately, the situation is never as simple as this. Each decision on design, equipment, procedures and so on involves a great deal of balancing of advantages and disadvantages within the field of safety.

I might take the question of oxygen masks for pilots as a good example of this. From the point of view of speed of reaction to a sudden loss of cabin pressure, the ideal method is to have one or both pilots wearing masks the whole time. Medical evidence shows, however, that this may be a burden and may result in an overall drop in efficiency during every flight. Should the operator risk a lower standard of efficiency on every flight in order the better to guard against an eventuality which might occur once in 10,000 flights?

Similarly, it is sometimes argued that the operator should be prepared to install any equipment which could increase safety. This argument ignores the fact that more equipment may mean more complexity, more chance of unserviceability at a vital moment, and more operating workload on the crews. Once again the operator must decide between different courses, each of which may appear to lead to the safety summit.

How does the operator set and maintain his standard? To some extent he is guided by State legislation which generally lays down a minimum standard in certain areas of design, maintenance, crew training, health and so on. It has always been a cardinal principle, however, that the ultimate responsibility for operational standards and safety rests upon the shoulders of the operator and he alone can discharge it.

In carrying out this task he is faced with a number of difficulties, not the least of which is the lack of an absolute standard, to which I have already referred. Perhaps his most valuable guide to setting the right standard is his primary loyalty to and responsibility for the welfare of his passengers. This takes several forms, including safety, comfort and punctuality. He must also be in a position to charge a reasonable fare, otherwise his would-be customers will not be in a position to take advantage of his excellent services.

Conflicting Demands

It is apparent that these requirements may be to some extent contradictory. If the operator decides that the safety of his passengers demands a wing structure that will not break even under the greatest provocation, the result may well be an aircraft with virtually no payload. He may have to be content with a wing that is adequately strong for all but the most extreme conditions which he judges will be encountered only once in many millions of flying hours. Similar considerations apply when we consider such matters as operational weather minima. It would be easy to lay down minima which would make it virtually impossible to run into trouble through the presence of low cloud or poor visibility on the approach, but the effect on regularity and punctuality would be disastrous. Once again the operator could not remain long in business because nobody would ever travel in his aircraft knowing that there was every possibility of delayed departure or a diversion from the destination. Taking into account such factors as the excellence or otherwise of the landing aids, the surrounding terrain and the type of aircraft, the operator lays down figures which will allow his well-trained crews to operate into each airfield with a high degree of safety and regularity.

In these and a hundred other ways the operator is daily brought face to face with the necessity for balancing an increased degree of safety against the effect and cost of the change. In many cases the decision is easy to take because the issues are clear cut, but difficulties arise in the marginal areas where the advantages may not be wholly proven or the probability of incident is of a very low order. Clearly the operator's standard must be set at the highest level consistent with operating efficiently as an airline. Should he fail to achieve this balanced view of his responsibilities the efficiency of the airline will suffer. If, for instance, he should lay too much emphasis on regularity and punctuality he may influence his pilots to fly in unsuitable weather conditions. If he insists on very great strength he may not be able to carry economic payloads.

Public reaction is an important factor in Air Safety. As far as the public is concerned, one accident to an aircraft of Operator A which has 10 aircraft is equivalent in importance to one accident to Operator B which has 80 aircraft; therefore Operator B has to maintain, if I may use the expression loosely, "eight times" the safety standard and eight times the safety effort of Operator A in order to achieve the same overall effect. This unfavourable public reaction to one airline suffering several accidents provides an effective check on the safety standards of a big airline, whereas a smaller operator, if he were lucky, might get away with lower standards for a considerable period.

Risk Prediction

It is my contention that, far from being in any way immoral, this process of weighing up the importance and likely incidence of any particular hazard is part of the everyday experience of life without which progress of any sort would be impossible. If we decide that it would be desirable to state the acceptable risk in quantitative terms in order to have our aims more clearly in view, this seems to me to be a more scientific approach than the purely empirical methods which have too often been employed in the past. It is unfortunate that humanly speaking none of us reacts too favourably to such attempts to achieve accuracy in risk prediction —the process invariably has a flavour of acceptance that a certain number of accidents will inevitably occur—which nevertheless is a fact. Naturally this concept is particularly repugnant to the pilot and other flight crews, whose lives and livelihood are more intimately bound up with flight safety than anyone else in the business; nevertheless, we have to face up to the fact that accidents to aircraft will continue to happen in the future as in the past. An operator's job is to see that they are no more frequent than they have to be.

The Human Factor

This brings me to my next point, which is the growing importance of the human factor in flight safety. In an age when automation is being introduced into so many processes, the art of flying retains much of its reliance on the skill and knowledge of the individual pilot. It is true that he has been given many remarkable aids and that the machines which he flies are infinitely more sophisticated than those of even a few years ago, yet the pilot still holds the key position. Failure rates of what our American friends call "materiel" are falling year by year, whereas the rate for human error remains fairly constant, with the result that it forms a greater proportion of all causes. There is no suggestion that the word "error" implies guilt in the person responsible and I wish, like the correspondent in *The Times*, that we could find another phrase for "human error." In the past 50 years Man and Machine have taken immense

strides, but in recent times it is doubtful whether the one has kept pace with the other. When I use the term "human error" I do not of course accept that in every case this is synonymous with "crew error." Human shortcomings in basic design often play an important contributory part in leading to an accident. I think that the growing co-operation between the aircraft manufacturer and the operator is a vital part of our efforts to develop a combination of man and machine which will not have built-in accident characteristics.

Just as today's pilot must possess a combination of many skills, so the aircraft is becoming less of a pure flying machine than an integrated system for carrying out a specific function. In military parlance it is usual to speak of some of our more advanced types as "weapons systems"; I suggest that the time has come to look upon the transport aircraft as an "air transport system." To produce a successful air transport system it is necessary to think not only of airframes and engines, but of radio and navigational equipment, loading facilities, emergency equipment and passenger amenities. You may think that there is nothing new in any of these items, but I suggest that it would be a new advance if we could think of them as part of an integrated system rather than as a list of unrelated requirements which must somehow be fitted into the strait-jacket of the airframe.

The connection with flight safety should be self-evident. An aircraft system which has been designed to work as a whole, operated by a crew which has been trained to think of the job in the widest terms, is almost certainly going to be safer and more efficient than a combination of piece-meal design and training.

The development of the highest degree of flight safety demands a continuing effort on the part of each one of us, designer, operator, pilot, engineer, whatever our particular niche in the structure. It is no use leaping ahead in airframe and engine design if this progress is not matched by developments in communications, navigational aids, air traffic control and the efficiency of human operators.

Here lies our greatest challenge; the human mind appears to be capable of almost unlimited development, but is fatally prone to follow well-defined paths. The operator must ensure that every opportunity and encouragement is given to his staff, especially his flight crews, to train their minds to think in terms of tomorrow's needs and demands rather than those of yesterday.

All our development must advance equally on a broad front by adopting what has been called the "doctrine of parallelism." In this way we can be sure that we have at all times men, machines, and methods which are able fully to meet the demands made upon them.

Standards Built on Experience

An airline's safety standard, whether quantitative in terms of design factors and weather minima, or qualitative in such matters as information, discipline and medical, are the result of many years of experience, much of it expensively gained. As each day passes fresh knowledge is added to the store of the past, knowledge which may involve changes in long-standing habits and beliefs.

Sometimes it takes years to see the full fruition of ideas which had their birth in some accident or incident. When I was preparing this paper I came across the report on an approach accident some years ago, in which it was recommended that the question of improving methods of crew co-operation should be studied. This was the germ of the idea of the monitored approach which is now the accepted policy in at least one airline I know.

For those to whom the term is unfamiliar I should perhaps explain that a monitored approach is the logical outcome of a well-developed scheme of cockpit management. It puts into practice the theories that "the onlooker sees most of the game" and that "a person watching you is more critical of what you are doing than you are yourself." We can no longer afford to have the various members of the flight crew doing their various jobs in splendid isolation from each other, as this leaves too much room for errors to go undetected. In the case of the two pilots there is a system of constant cross-checking of each other's activities to ensure that no item is omitted or wrongly performed.

This process is carried a stage farther during the approach and landing phase, where one pilot does the instrument let-down, monitored by his partner, who takes over the controls only when he has established firm visual reference with the approach lighting. In this way one avoids the dangerous situation in which the pilot is giving part of his attention to his flight instruments and part to the establishment of visual contact. If contact is not established and an overshoot is required, the pilot who has been on instruments remains in control, his continuity of reference has been undisturbed and the result is a more effective and better integrated operation.

This is only one example of a considerable step forward which has occurred as the result of operating experience. No doubt you can think of many others in the fields of engineering and operations which have come about as the result of accidents and incidents. I need only mention such instances as the tank testing of new type aircraft, engine fire extinguishing systems, crew checks and drills, performance requirements and the introduction of the runway visual range and so on.

Accident Prevention

It is impossible to over-stress the importance to flight safety of this process of learning from our mistakes. By "mistakes" I do not mean only the accidents but also the incidents which might have been accidents. Here we enter the field of preventive flight safety. "Prevent" originally meant "go before." How much better to have flight safety going before us rather than following some mishap or other. I agree with General Caldara, Deputy Inspector General of Air Safety, U.S.A.F., that incidents are the most valuable barometer for flight safety. They can warn us of the area in which danger lies, and if we watch them carefully and take

remedial action in good time there is every possibility that we shall avoid a serious accident.

I doubt whether we have in the past laid enough stress on forward thinking in relation to accident prevention. I do not know who first coined the apt expression "Murphy's Law" but I think we all owe him a debt. How many accidents have occurred through our failure to observe the workings of the law, that if it is possible to do a thing wrongly, somebody will do it. This is particularly true of design faults which enable vital controls and pipes to be assembled incorrectly, but I do not doubt that its evil effects could be found in many other situations. All of us who have any responsibility for design or the issuing of instructions should have Murphy's Law constantly in mind.

Independent Air Safety Branch

A responsible and efficient operator maintains a watch on all aspects of flight safety by a ceaseless interchange of information through a Branch which, in my opinion, should be independent of any particular operational or executive department. I cannot overstress the importance of having within an airline an independent Air Safety Section to investigate incidents and accidents and advise on all aspects of accident prevention. It should be the operator's policy to give the most free circulation possible to much of the information which is in many organisations kept on a confidential basis. Although my airline did not at first receive much reciprocation, in the past two or three years there has been a growing realisation of the value of this exchange. For its full development, this idea involves the creation of an atmosphere of mutual confidence and a deeply held belief that the needs of flight safety transcend individual and sectional interests and commercial rivalries.

International Co-operation

I would like to see our ideas on exchange of information extend to include other United Kingdom operators and then our European friends and finally to be developed into a world-wide organisation. Perhaps the Flight Safety Foundation of New York could then become the Flight Safety Foundation International. In the meantime I welcome the formation of the new Transport Flight Safety Committee with its object of collating and distributing flight safety information within the United Kingdom. I hope that all who have suitable material will see that it goes into the common pool of knowledge so that ultimately all may benefit.

Communications

Communications, whether in the technical sense of radio equipment or in the sense of passing information of every sort between individuals and organisations, lie at the heart of the flight safety problem. I came across the statement the other day that in almost every case of air accident there was somebody somewhere, perhaps a pilot, an engineer, a metallurgist or a met. man, who had the answer if only the communications had been good enough to get his information through to where it could have been acted upon.

I conceive one of the operator's most important duties to be the provision of adequate information channels horizontally and vertically throughout his organisation. His instructions must be clear and concise, he must give all the information needed. He must exhort his employees and let them know how their efforts compare with others in similar fields. He must at the same time provide means for effective feed-back of information and for taking the appropriate action if that is indicated.

I think the operator is falling down on his job if he fails to make the urgency of flight safety permeate his whole organisation. Even those such as accountants, personnel and sales staff, apparently remote from direct contact with operations, should do their jobs in the knowledge that the approach they make to their work ultimately affects the organisation's attitude to efficiency and safety. This is, I think, part of the wider problem which every big airline operator faces—the difficulty of giving all the varied professions and trades a sense of belonging to a unified organisation, of giving them a single aim and a sense of "belonging."

Specific safety problems should be tackled by specific means. For instance, one must be very conscious of the seasonal weather changes and make special efforts to impress on engineering and operating staff the dangers of any complacency which may have been induced by a period of fine summer weather. This is another aspect of flight safety where closer co-operation and pooling of ideas and experience between operators could pay dividends. None of us has all the answers, but by getting together we could certainly increase our knowledge.

The operator has many safety problems, some within his control, and some outside, and only a few of them can be touched on here. Apart from such questions as design factors and weather minima, he has to decide, within the framework of State Legislation, what degree of training he shall give his operating crews, how often they should be checked and what methods he should use and so on. Time forbids a lengthy treatment of this very relevant topic, but I might mention the question of flight simulation. I have weighed the value of simulator training and have found that, quite apart from economics, it has enabled a far higher degree of competence to be attained, especially in dealing with emergency situations.

Recent incidents involving large jet aircraft on training flights tend to highlight the dangers of attempting to carry out realistic training in emergency procedures in an actual aircraft. Is the operator justified in hazarding the lives of his crews and a valuable aircraft in attempting this sort of training? Many operators are coming round to the view that not only is it unwise but it does not succeed in its aim to the same extent as electronic simulator training.

Practical Steps to Safety

As I have been asked the operator's point of view, I feel I should outline some of the practical steps which an operator might take to ensure that he is setting a high standard of safety and, equally important, that he

is maintaining that standard consistently throughout his operations. I can only touch on a few of the aspects, but they will serve as examples and reflect what is happening in my airline.

I have already demonstrated the difficulty of deciding what constitutes a correct standard, a difficulty which is made worse sometimes when many authorities are giving their opinion. Therefore I suggest that on the operational side of the house the responsibility for laying down operating and training standards may best be put into the hands of two small groups comprising senior officials in the respective fields. By meeting at regular intervals, scrutinising all operational and training standards and methods, and recommending appropriate action, a high degree of uniformity may be achieved, even in a large organisation. These recommendations, if accepted, would then lead to corrective action through the normal processes of instructions to flight crews and routine check flying.

The Engineering Department would have an inspectorate exercising quality control throughout its organisation, whether at base or along the route network. In order that incipient troubles may be quickly notified and dealt with, it is most necessary that there should be quick and easy means of communication up and down the lines, workers at all levels being well-informed of changes in procedure, modifications and so forth, and being encouraged to report unusual occurrences and difficulties.

There should be an effective system of inspection, reporting and corrective action in every section of the organisation which has a direct connection with flight safety. The control of vehicles on the airport aprons, passenger handling, catering and baggage loading are all matters which require constant checking to ensure that the most safe and efficient methods are being used.

Every airline should have medical staff or inspection including specialists in aviation medicine, charged with responsibility for promoting good health and well-being among the staff, for watching for deterioration in medical standards and inspecting buildings and facilities. No operator should tolerate sick men, either in the workshop or in the cockpit: the risk is too great.

I have already referred to the value of having within an airline an independent Air Safety Section, to investigate incidents and accidents, and advise on all aspects of accident prevention.

International Activities

In all the ways I have talked about, and many others, the operator discharges his responsibility directly, but what of those activities which lie outside his immediate control? The most obvious examples are the services provided by his own Government and by other States, airports, met. facilities and air traffic control. He must do his utmost through his own efforts or collectively through such international organisations as I.A.T.A. to ensure that States do supply him with the standard of service which he requires to maintain his own standard of flight safety.

The efforts of I.C.A.O., I.A.T.A., I.F.A.L.P.A., and other international bodies have resulted in great strides forward in many of the fields I have mentioned, but much remains to be done. The situation is not static, air traffic is growing, aircraft are flying higher and faster, so putting ever-increasing stresses on the existing services. The operator cannot afford to be complacent about these changes; he must be planning ahead and giving the lead.

Conclusion

There is nothing in the present situation which can give the operator cause for complacency—in fact, there never will be. He must always be in a state of "restless dissatisfaction" with his safety record, with his safety standard and with his safety precautions. He must be ever testing his efficiency and his methods against the standards set by others in the same field, and then going one better—if he can!

How successful have the world's airlines been? Today most passengers climb aboard our aircraft with little more apprehension than they would when jumping on a bus. This is a crude but significant measure of our success. In bringing air transport within the reach of millions of ordinary people we have had to lift it out of the realm of the sensational and place it firmly among the normal activities of the public. We have got to the stage when we can and do tell our passengers what we are doing and providing for their safety without creating alarm in their minds. I believe we make them feel safer by doing so.

The trend of the accident rate on a given number of movements is steadily downward, a sign of our success in achieving greater safety in the air; but I must point out that the increase in the total number of flights may lead to the paradoxical situation that a greater number of accidents may be recorded unless continued efforts are made to give effect to the doctrine of parallelism. An added incentive to greater efficiency and safety must be the knowledge that passenger aircraft are getting very big.

I end as I began by saying that "Safety is no Accident"; it is not the product of haphazard, piecemeal thinking; it is not gained by leaving tomorrow's affairs to take care of themselves. The operator's view of flight safety must be all-embracing; scanning the past for lessons to be incorporated in the future, watching the present for every sign that may indicate a weakness or error in planning or execution. There is no end to this task; the curve of the safety graph flattens out towards the top, until each further improvement requires many times the effort required at a lower level. It is an effort which every operator must make if he is to serve faithfully the cause of flight safety.

The Airline Pilot's View

by

Captain E. C. MILES

(British Overseas Airways Corporation)

BEFORE EXAMINING the Airline Pilot's views on Flight Safety, a brief look at this Airline Pilot will be taken to get a rough idea of the viewpoint from which he speaks.

The Chairman, in his opening remarks, referred to pioneering. In the early days of aviation the pilot was a pioneer, and as such he had to take risks. At the present time, and in some parts of the world many years ago, the pioneering adventure of flying has grown up into a serious transport industry, and the airline pilot has grown up with it. Today, the airline pilot is an executive of that transport industry; a highly skilled employee or a highly specialised manager depending on the way you look at him.

In any event the airline pilot is a man who makes his living flying scheduled and non-scheduled flights. On the world wide average he flies, I suppose, on roughly half the days of the month and spends about 800 hours a year in the aeroplane. He hopes to spend at least 25 years of his life in doing so.

It is from this viewpoint that the airline pilot examines flight safety and from this viewpoint the airline pilot considers Flight Safety to be something sacred. In the decisions he has to make concerning his conduct of the flight, safety is the prime consideration. Before he gets airborne, a rough running engine, a mag. drop or a plug out on the analyser, and he has to return to the ramp to get it fixed; a suspicion voiced by the meteorologist that the forecast for an alternate is optimistic and he has to find another. In his own handling of the flight, the pilot is in control; safety is assured as far as he can assure it.

This does not mean that he ignores the economic aspects of his professional task. The slogans of two pilots' associations, "Service with Safety" and "Schedule with Safety" are true representations of the pilots' outlook.

But, although the safety during flight rests in his hands, he has seen that activity on the aeroplane is not enough. The navigational aides *en route* are supplied by governments, the equipment on his aeroplane is purchased by the operator, the aeroplane itself is certificated under government authority; in fact the whole area in which he works is regulated by one authority or another. All of these items are tools for his trade and he decided that he had a responsibility to step in and make his practical knowledge available to the designers and purchasers of these tools.

Since taking the first step in government and international regulating authorities, pilots have become increasingly active in this safety field. Through their professional associations individual airline pilots provide a cross-section of experienced opinion on the subject, an opinion which is remarkably unanimous throughout the world. When this pilot opinion decides that some specific area of flight is subject to a safety hazard, then through members who have made specialised studies and through paid secretariats they prepare a documented case for presentation to the regulating authority or the industrial body concerned.

Although the airline pilots have had a great success in improving safety standards, they continue to be amazed when, upon pointing to an obvious danger area, they receive a negative response. Until recently they have assumed that the lack of action from the body referred to was due to lack of understanding on the part of individual officials or to weaknesses in the presentation of the pilot's viewpoint. But the pilots are slowly coming to the conclusion that the other members of the aviation industry are taking a view on flight safety which is completely different from their own.

Pilot representatives are still astonished to find a committee concluding its deliberations on an area of danger with the words "This is a risk we are prepared to accept". As he settles into the flight deck after a meeting the pilot representative becomes somewhat indignant at the manner in which the committee members accept the risk. But I want to emphasise that so firm is the pilot's view that safety is sacrosanct that he puts these others' views on safety down to the incompetence of the individual rather than to the official view held by a part of the industry.

So firm is the pilot's view that safety is sacrosanct that he cannot yet believe that others in the industry do not share his view. One of the leading pilot representatives on Flight Safety at a meeting preparing regulations on safety, at one point said in astonishment "But this is a matter of safety. You can't negotiate safety". The Chairman of the Meeting looked at him and said "And just what do you think has been our purpose in sitting here for the last few months?" If, then, the airline pilots' view is that safety is not to be negotiated, what is the view of the other members of the industry which he is now learning differs from his own?

Let me make use of quotations by people other than pilots so that I do not misrepresent those views.

"In most human activities there is an element of risk. If we choose to indulge in a particular activity it is because the benefit from doing so more than compensates for the risk. Air Transport is no exception. It offers the advantages of speedy travel and if we view our time as being of sufficient worth, the risk is accept-

able. Again, it is usually possible to reduce the risks by applying greater effort of man power and hence expenditure of money. In other words, safety is a purchasable commodity. Within limits, this is so of safety in air transport. In most countries the government assumes the responsibility of determining the level of risk acceptable to the community".

This raises two questions. Firstly, in the quotation it is said that "The government assumes the responsibility for determining the level of risk acceptable to the community". Is the government's responsibility limited to ensuring that the risk does not rise to such a level that passengers start to refrain from flying? Or has it a responsibility to demand a higher level of safety than the passenger would be prepared to accept? The question is important, for passengers are probably in greater ignorance of flying than any other form of transportation. That is not to say that they cannot read the accident statistics but they are in a weak position when it comes to realistically assessing the risks involved. The pilot believes, therefore, that the government—or any regulating authority—has the responsibility of ensuring the highest achievable level of safety is provided.

What then is the pilot's definition of the highest achievable level of safety?

The airline pilot says: "Remove all foreseeable or suspected causes and accept the unforeseen, unforeseeable accidents. Once they become foreseeable prevent their occurrence; once the unforeseen happens, prevent its recurrence".

This is sometimes taken as a demand for absolute safety and is countered by the argument that absolute flight safety can only be attained by no flight at all. This is not a valid objection to the pilots' arguments. The pilot merely regards it as axiomatic that all known or suspected specific causes of accident shall be removed. He accepts that accidents will happen but he believes that as the name implies they will be accidents.

Secondly, since the government goes to such lengths in assessing and checking the safety calculations of flight should it not, if it is balancing safety and economics, go to similar lengths in checking the economic calculations of flight? Let me give an example. During negotiations over new Performance Regulations, a pilot representative was told that his representations for no lowering of the take-off safety speed margin were not acceptable since proposals for the retention of the higher existing speed would reduce the payload to an uneconomic figure. The aeroplane went into operation. Some time later the take-off speed was in fact increased by some 7 knots. The airline is still operating and, I believe, at a profit.

Let us examine this economic aspect further. Let us assume that we are agreed that it is necessary to lengthen runways to improve safety. Certainly this is an economic penalty. It costs the State or the community a lot of money to put down more concrete. However, we put it down and now the aeroplane can take off and land in safety and the airline runs at a profit. But what happens next? The manufacturer builds and the operator buys an aeroplane which uses the same proportion of this lengthened runway as the previous aeroplanes did of the shorter runway. The pilot objects that this is reducing safety. But the operator says that unless he can use the higher proportion of runway, he will go out of business. Yet, he did not go out of business with his previous aeroplane when they lengthened the runway. So what did we achieve with the extra concrete? Better economy—not safety. And then it is said that safety is expensive.

When one examines the history of aviation one can see this happening over and over again. For example:—

Landing speeds are too high	Flaps bring greater safety. Then the speed is put up again and the old danger has returned.
Landing aids improve safety	Then the landing weather limits are lowered and safety goes down again.
Automatic Feathering improves safety	Then the take-off weight is put up. Safety goes down again.

So the question raised, then, is: are safety authorities being persuaded by the operators into accepting lower standards than those standards which are economically feasible?

Now let us look at another quotation from the viewpoint other than the pilots'.

"One of the features of a fully rational approach is that it becomes necessary to take a conscious decision on how frequently we can accept an accident or an incident from a particular cause. There is a resistance to this. It is more comforting to take the view that so far as one knows an accident will never, or almost never, occur, than to declare that once in a given (though large) number of occasions an accident is expected. However, I believe that the former view is simply shirking a responsibility. In so many Airworthiness fields total avoidance of accident is impossible. Thus accidents will occur at some frequency and once we know sufficient about the particular matter, this frequency becomes predictable. Once it is predictable, we can no longer avoid deciding the acceptable value".

On this question of probabilities, one might calculate that at a particular blind cross-roads, say between 2 and 5 a.m., the chances of encountering another car at the crossing were 10^{-5}. But one would still be very foolish to drive blindly across, when by stopping and looking one could reduce the probability to zero. This then is one of the pilot's criticisms of the probability concept. Probabilities help to calculate a margin but a margin is not always an acceptable replacement for a parameter. The pilots do not disagree completely with the probability concept. In some cases they disagree only with the incident probability accepted. In other cases they believe the concept leads to the acceptance of accidents which need not occur at all. We find today that the probability concept, admirable tool that it is, has run wild.

Altimeters are an example. We have aeroplanes flying within 333 yards of one another, separation

maintained only by a barometer. Laterally the separation may still be 150 miles. And we use the probability of two aeroplanes being in the same spot at the same time in order to calculate the acceptable tolerances of the barometer. The probability concept is useful provided we remember that there is still a probability of zero.

One of the other ways in which the probability approach is affecting flight safety is the acceptance of the present accident rate as being just about right. Thus there exists a complacency which is entirely unwarranted.

Sometimes when the airline pilots put forward a case for improved regulations the answer comes back "How many accidents is it suspected that this factor has caused? If the number is small then there is no need to take any action as the probability is a remote one".

When one looks at the accident record of civil aviation one can be justifiably proud of a good record. But that is no reason for failing to improve the record where it can be improved.

And it must not be forgotten that the passenger-mile criterion is an extremely favourable one for civil aviation. I am not going to dwell on this point since it really requires an Insurance representative to do it justice. But the airline pilots' view is that the safety record is not a terrifyingly bad one, that it is capable of being improved, but that in fact the Industry is, if anything, allowing it to worsen.

Let me finish by pointing to some of the areas the airline pilots consider to be most dangerous at present —in order of importance.

Landing. Here is an example of the cause of the danger being well known and proposed remedies already existing. There is a wide discrepancy between the procedures used in measuring the landing distances for certification purposes and the procedures actually required for day-to-day operation. There is international agreement that the present requirements are unrealistic and the Air Registration Board is to be congratulated on having written an alternative requirement. However, it is only an alternative and aeroplanes are still being certificated to known unrealistic procedures. Also in the area of landing there is need for improved approach aids and world-wide installation of approach aids. But these aids must be related to a landing distance based on the needs of day-to-day airline operation.

Take-off. This is largely a problem of runway lengths and speeds. The existing new regulations for turbine-powered aeroplanes may be just about right but the margin is extremely narrow. The pilot believes that when a new type is introduced, in this case jet as opposed to propeller, the margin should be increased rather than decreased during initial introduction.

Mid-air collisions. This is a field of great danger today. The concept of see and be seen is unacceptable. The only solution is to provide positive separation by means of Air Traffic Control.

The Accident Investigator's View

by

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(Chief Inspector of Accidents, Accidents Investigation Branch, Ministry of Aviation)

WHEN I WAS ASKED to take part in this Symposium it was suggested to me that I should talk about the Accident Investigator's view on Flight Safety. Now I do not suppose that the accident investigator's view is very different from the view of anyone else working in the safety field. The whole object of flight safety is to prevent accidents and the whole object of the accident investigator is to ascertain the causes of accidents so that remedial measures may be taken.

We must discover the causes of accidents before we can stop them and I make no apology for repeating this. Now the theme of this short paper is simply this, that while the precise causes of accidents have in general never been easy to ascertain, during the past few years the difficulties have increased enormously and it may well be that in the not too distant future, unless the problems involved are recognised, and faced, the causes of accidents may either not be ascertainable at all or not be ascertainable precisely enough to enable effective remedial measures to be taken. If this should happen, and present trends indicate that it may, then I submit that the very keystone of the arch of safety will crumble away.

What are the problems involved? Why is it becoming so much more difficult to find the cause of an accident? The answer lies firstly in the fact that since the modern aircraft now daily spans the world in almost every direction, it can crash almost anywhere in the world and that when this occurs in the sea or in any area remote, sparsely inhabited or not readily accessible, the chances of finding the cause are seriously diminished; secondly, and as might be expected, in the tremendously increased and ever increasing complexity not only of the aircraft and its control systems but in every other service both in the air and on the ground associated with its flight. In the modern aircraft we have a very large, complicated, but easily disintegrated

structure, propelled at extremely high speeds at great altitude and controlled by means of advanced and novel systems operated through black boxes by electrical, hydraulic or other means. In addition this structure, which burns comparatively easily, carries an immense quantity of highly inflammable and potentially explosive liquid. In addition to all this the whole system is largely automatic, while communications between any particular aircraft and the ground is fast approaching a minimum.

Let me first sketch the great difficulties the investigators in the field are now up against. The immense task of investigating a major accident to a modern aircraft is certainly hard to comprehend except by those called upon to do the job. A well-known multi-engined aircraft—comparatively small to some now flying and in the course of construction—has an all-up weight of approximately 80 tons. When one is confronted with an accident to such an aircraft the scene is often one of utter destruction and the technical problems involved may cover the whole diverse field of aviation. In any accident there is no substitute for the diligent and thorough investigation by experts and such investigations cannot be done quickly or cheaply. Guesses, hunches, jumping from one thing to another (a common error on the part of inexperienced investigators) can only lead to vital information being lost. Accidents vary so much in size and severity that it is not possible for me in the time available to select more than one class, but what I have to say about this can very largely be applied to most of the others.

I have chosen as an illustration the accident which involves a break-up in the air of parts of the aircraft's structure. The results of such accidents can vary enormously in extent but all of them are serious and can have very wide and far-reaching repercussions. When an aircraft breaks up in the air the wreckage may be distributed over many miles of country. The extent of distribution is a function of height and speed and 25 square miles is not altogether unusual. The type of country over which the disintegrating aircraft falls is, of course, a matter of chance. It may be mountains, swamp, desert or sea or a closely built-up area or indeed a combination of these. The accident may happen anywhere in the world and the climatic conditions can vary from the Arctic to the Tropical belts.

Following a major structural failure to a modern aircraft the scene on the ground can be visualised as roughly equivalent to the effect of scattering the fragmented wreckage of ten double-decker London buses, crushed, twisted and burnt and often buried in the ground to depths of up to 60 ft. and separated perhaps by many miles. I make no comment on the grimmer details except to say that the investigators, for nowadays a team is necessary, may well have to concern themselves with these in the interests of reaching a solution to the accident or in providing specialised data upon which future safety measures may be taken.

No one, I hope, will think I have exaggerated the picture for indeed I could hardly do so. I have made no mention, for example, of the many human problems connected with the investigators themselves. They must keep themselves vaccinated and inoculated. They must be prepared to leave home at short notice for any part of the world at any season of the year. Keenness, physical fitness and endurance must rank high in their attributes. Without these they may never get to the scene of an accident or be able to withstand the rigorous and indeed hazardous conditions which they are often called upon to face. Whatever their technical qualifications may be, they are of little use unless they are able to apply them at the scene of the accident. Purely as a matter of fact, investigators from the British Accidents Investigation Branch have since the war visited over 40 different overseas countries, many of them more than once. They have travelled from the Andes in the west to Hong Kong in the east and from Iceland in the north to Zanzibar in the south. They have trekked in Brazil and Nigeria, in India and the Sahara and they have climbed the Alps, the Pyrenees and the mountains of Sicily and Sardinia.

This then is the overall picture and from it arises a number of considerations. Before we can begin to find out the cause of an accident we must be able to get the investigators physically fit, properly equipped and suitably clothed, to the scene of the accident in whatever part of the world it may be. Moreover we must be able adequately to maintain them at the scene of the accident for as long as may be necessary. To do this they must have the support of an organisation capable not only of meeting their requirements in the field but also of fulfilling all the heavy technical demands which may later arise. Light and heavy surface transport, heavy lifting equipment, earth shifters and diggers, light and heavy water transport, freight aircraft, helicopters, sea salvage units, photographic units, the possible field requirements are indeed staggering but nevertheless experience has indicated that without the ready availability of such facilities the causes of accidents may go undetermined.

The cause of a major accident can seldom be positively ascertained in the field and particularly is this true of the structural failure type of accident. In almost all cases when the essential field examination has been taken as far as it is possible to carry it, the wreckage must somehow be transported back to a centre where it can be assembled and examined under suitable conditions. An immense amount of work and money may be involved in this.

The aircraft may have been completely disintegrated by the forces of impact and perhaps 50 tons of wreckage reduced to comparatively small fragments have to be identified, laid out and built up into some semblance of an aircraft. After that has to come a careful analysis of almost each fracture in an endeavour to establish the primary failure and why it occurred. The structural failure of an aircraft in the air need not of course be due to any weakness in the aircraft itself but this can in general only be established after the build-up has been completed and the fractures studied. The provision of large suitably equipped hangars, sufficient men trained in the work of wreckage assembly and analysis, together

with access to appropriately equipped test laboratories are absolute necessities.

Those of us who were closely connected with the investigation into the early Comet accidents will know of the immense effort which necessarily had to be made so that the causes could be determined. Every facility of which I have made mention was used. Indeed when one considers the resources which had to be called into action the operation developed into a national effort.

It would be totally wrong to suppose that the investigation of a major accident to one of the oncoming jets for example, could be undertaken solely by a comparatively small accident investigation branch. The professional investigators must be supported by a system which is capable of quickly bringing into action all and every facility as required. These include government aeronautical establishments and laboratories, facilities possessed by the Navy, Army and Air Force and facilities possessed by the operator and by the constructors of the airframe, its engines and equipment. In addition I know that no accident to a modern aircraft can be investigated successfully unless professional investigators are also able to have the wholehearted co-operation and assistance of all those people possessing the specialised knowledge of the problems involved.

As Chief of the British Accidents Investigation Branch I would say this; we have no illusions as to the magnitude and ever-increasing difficulties of our job. I know we have not got and never can have the knowledge to contend with the multitude of specialist problems which may arise. The successful investigation of a modern accident depends upon team work. We want and would welcome your help. We want the help of the constructors of the aircraft, of the engines and of the equipment. We want the help of all those who have to operate and fly the aircraft. We want the help of your Societies and your Associations, of your Guilds and your Boards. We want the help of all who can assist us. We act in the interests of flight safety—which is your interest. So if the opportunity comes your way, join with us—we have only one aim, to find out the causes of accidents regardless of how the chips fall.

Accident Sites

Although Fig. 1 shows an accident site of the very early 1940s it illustrates well enough a number of points broadly applicable to accidents during the following decade and indeed into the 1950s. The Investigators can tell on inspection what kind of aircraft it is. Note that the whole aircraft is confined within a limited area. Although the aircraft is a "write-off," from the viewpoint of the Investigator the damage is comparatively slight.

Note that the ground is hardly disturbed, even although this aeroplane came down out of control from 8,000 ft. Wing, tailplane and fin attachments can be checked. Every control surface can be inspected for attachment. The control runs, cable and push-pull, can be examined. The trim tabs can be inspected. The Investigator can determine from the wreckage what manoeuvre the aircraft was doing when it struck the ground. From the propeller he can adduce what degree of power the engine was developing. Fuel cock settings and cockpit instruments are available. Fire, that biggest destroyer of evidence, has in this case not occurred. In general, because the speed and weight of the aircraft of this period were comparatively low, the damage to the structure was low and it was rare to find any part of the wreckage embedded more than a few feet in the ground. Since too the average operating heights and speeds were so much lower, witnesses on the ground could generally see and follow the manoeuvres of the aircraft and give a good account of what they saw, a very important factor in accidents investigation largely missing today.

Although the accident shown in Fig. 2 occurred at the beginning of the 1950s almost all the remarks applicable to the last accident are also applicable to this. In accidents of this size however the investigating effort has to be greatly increased. The picture clearly illustrates too the heavy calls on transport of all kinds which can arise. Quite apart from the transport shown in the picture, before any serious technical examination can take place heavy lifting equipment and transporters have to be brought into action, as well as a host of auxiliary equipment used during the dismantling of the structure. If this accident had occurred in an inaccessible place abroad the difficulties facing the Investigator are obvious.

Again, Fig. 3 shows an accident which occurred a few years ago. The aircraft struck steeply sloping ground after almost all forward speed had been lost. It seems likely that on impact the aircraft suffered comparatively little damage but a fire which quickly broke out has virtually destroyed it. Fire is the greatest destroyer of evidence. In a few minutes it can reduce a whole aircraft to little more than a heap of metallic dust interspersed with some distorted ironwork. Possibly podded or tail engines may reduce this risk but until it is overcome the Investigator's work must inevitably suffer.

Bringing you right up to date, Figs. 4–7 show recent accident sites involving modern aircraft.

I consider that Fig. 4 and Fig. 1 epitomise without the need of words the whole subject of this paper. Now although this accident concerns a military aircraft we cannot draw any comfort from this for I could just as easily have chosen a similar illustration from the civil field. Increase in size would be about the only difference. The hole in the ground, over 30 ft. deep and quickly filling with water, was made by a pure jet aircraft striking the ground at an angle of about 40° from a height of about 1,000 ft. at an approximate speed of 250 knots. The whole aircraft was completely disintegrated and hardly any piece of wreckage was bigger than a tea tray. Every piece of this had to be collected, the hole had to be bull-dozed out and the recovered earth sifted and searched for pieces. Pumps had to be used to keep the water down. The wreckage had to be transported to a hangar where the long process of examination was carried out.

When one remembers, to take only one aspect, that

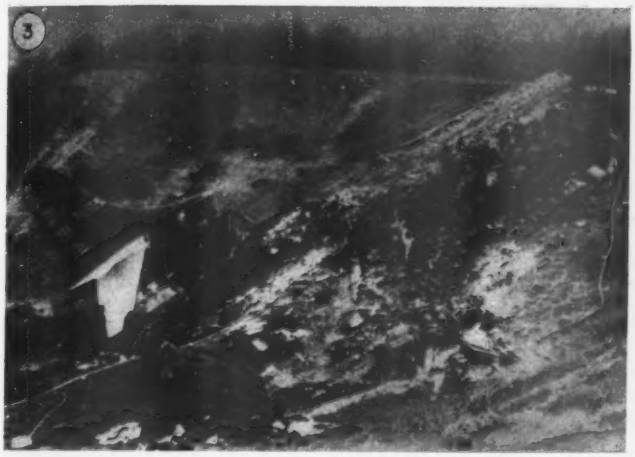

FIGURE 1. An accident site of the early 1940s.

FIGURE 2. An accident which occurred at the beginning of the 1950s.

FIGURE 3. An accident which occurred a few years ago.

FIGURES 4-7. Sites of recent accidents involving modern aircraft.

the modern aircraft is now controlled through a complex electro/hydraulic/mechanical power control system involving perhaps hundreds of relays, fuses, cut-outs, non-return valves, pressure accumulators, pumps, and so on, and that, depending upon the nature of the accident, all of these may firstly have to be identified and, incidentally, isolated from the many similar ones connected with the other services, and secondly examined in detail, at least one of the difficulties of investigating an accident to a modern aircraft becomes clear. I do not think I need enlarge further, the picture speaks for itself.

Figures 5, 6 and 7 illustrate what can happen when a large modern aircraft strikes the ground at a comparatively high speed. In accidents of this type the Investigators may find themselves having to deal with 60 tons of wreckage not one piece larger than a table top. If it is necessary to assemble and build up the wreckage before a detailed examination, the task is a huge one, for almost each piece of disintegrated structure has to be identified first. This is a long, difficult and time-consuming task.

Accident Investigators would be helped enormously if constructors would colour-code the basic interior structure of their aircraft. The port wing might be red, the starboard green. The centre section might be yellow and the fuselage blue. The tail unit could also be subdivided and suitably colour-coded. It requires little imagination to see what an immense difference this would make in building up, sorting out, identifying and assembling tons of disintegrated wreckage. At present the task is somewhat like trying to do an immense jigsaw puzzle without a guiding picture. Colour would provide the picture. Moreover, in the case of a structural failure in the air Investigators would gain valuable clues from a coloured wreckage trail.

I believe that the greatest aid to investigation at the present time is the crash recorder. In my view no modern aircraft should fly unless it has fitted into it an efficient crash recorder built and designed for the purpose. Fit and forget should be the aim. Recovery of the recorder intact should be certain under whatever circumstances the aircraft crashes.

Conclusion

As I said at the beginning, to achieve flight safety we must be able to find out the causes of accidents. I have tried to convey to you some of the difficulties involved. I believe that the world's aircraft constructors would be acting realistically if they assumed that any aircraft they built would meet with a serious accident either during the development stage or shortly after entering service. I know that unless the causes of any such accident can be determined beyond reasonable doubt the repercussions are certain to be serious. An unsolved accident, particularly one where the structural integrity of a new aircraft might conceivably be involved, raises serious doubts in the minds of the current users and also in those of the potential customers.

A great deal of study has been devoted to crash-proof worthiness but not to what I may perhaps call proof of crash worthiness. I believe that constructors should aim at building and installing into their aircraft as many means as it may be possible to devise which will assist in the investigation of any accident in which their aircraft may be involved. It would, I think, pay handsome dividends. Such means need not be complicated or indeed expensive and as a basis for consideration, and in conclusion, I summarise the following:—

(*i*) An efficient, recoverable, crash recorder.

(*ii*) Broad colour-coding of the interior structure.

(*iii*) Fire and impact protection for any vital black boxes which contain elements, the post accident settings of which would provide reliable evidence of pre-crash flight conditions.

(*iv*) Positive irreversible indications of the pre-crash settings of such items as gear, flaps, trimmers, fuel cocks—I have in mind "the number in the window" principle, mechanically operated by, and preferably located at, the main element. Remote electrical indicators rarely yield reliable evidence.

The Aircraft Constructor's View

by

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1. Introduction

Flight Safety is a subject which ranges outside the control of the Aircraft Constructor and so it has been interesting to learn the other points of view from the other papers. While it should be the natural aim to see that the aircraft matches the highest standard of safety, the constructor's control over this in the hands of the operator is limited.

It is impossible in a short paper to deal adequately with all the problems which concern the aircraft constructor. The aim of this paper is to examine in a broad manner the extent to which the constructor can contribute towards flight safety and to discuss the difficulties that he has to contend with and to suggest some methods to improve the overall safety level in the future.

I would like to say that I consider this opportunity of discussing flight safety has been well timed as in my opinion many Constructors, Operators and Airworthiness Authorities are doing some serious thinking on the flight safety aspect of current and new turbo-propeller and turbo-jet types. Also many new designs, including supersonic aircraft, rotorcraft, V.T.O.L. and S.T.O.L. are under consideration concurrent with the desire to increase the popularity of air travel. We have fairly strong opposing forces at work, on the one hand an increase in operating speeds with a possible lowering of the standard of safety and on the other hand an obvious need to increase the popularity of air travel by creating confidence in the air-travelling public by virtue of a good operating record. We have in this country some of the best designers and operators backed by an unequalled record for good workmanship and I believe our most urgent need is to build up a record of safe and reliable operation with British aircraft.

2. General Examination of Flight Safety

2.1. A DEFINITION OF FLIGHT SAFETY

The term "Flight Safety" covers everything which ensures the safety of the passenger and crew from the time of entering to leaving the aircraft. This involves the design, construction, testing, operation (including the operator and flying control) and maintenance. Here we see, as mentioned in the introduction to this paper, how far the subject ranges outside the control of the constructor, but this does not mean that he does not fully realise his responsibilities.

2.2. THE CONSTRUCTORS' RESPONSIBILITY—DESIGN SAFETY

No doubt every one of us connected with the aviation business has a different conception of what is meant by the term "Design Safety." We all know that the design of any aircraft is in fact a compromise between the various essential considerations. Design safety is that part of the design, including testing, which ensures complete safety of operation and creates a feeling of confidence in the passengers and crew at all times. Thus design safety, as understood by a constructor is not limited to the activities of the Design Office and should not be thought of within the limited scope of the detail designer (aerodynamicist, structural designer, systems designer and power plant installation designer) and the detail draughtsman. It also includes the design specification, compliance with airworthiness requirements and ground and flight development and these are all mentioned later in this paper. It must be appreciated that the staff engaged on these activities are all making a contribution towards flight safety.

2.3. HUMAN FACTORS AND THE DESIGN ORGANISATION

It is worth while mentioning here what I would term as human factors in a Constructor's Design Organisation, as there is bound to be a difference in outlook on the subject of flight safety as seen by the constructor's technical staff and those responsible for carrying on the business of regular passenger-carrying flights.

The technician or engineer, whichever you like to call him, is bound by virtue of his training and experience to pay most attention to producing a design which will give a maximum efficiency in operation. It is not always easy for him, limited as he is within the confines of a design office, to appreciate the full significance of design safety and airworthiness and in his struggle to produce an efficient aircraft the safety angle can easily rate of second importance. Again, not having the facilities or time to travel around the world and see for himself the practical day-to-day airline operation it is easy for the designer to think in terms of what he sees on the drawing board. In fact, in some cases we find reluctance even to follow the construction of the prototype and see for themselves whether their original conception has resulted in a practical design.

Associated with flight safety is the need to design for ease of maintenance. Poor maintenance can often be traced to a real difficulty in carrying out the work due to bad design in this respect.

I believe every aircraft constructor should have as part of its design organisation a separate section which is well equipped to give every possible attention to design safety which should lead to flight safety. It is all too easy to design an aircraft as a technical masterpiece and let the safety requirements look after themselves. The aircraft should be designed around the safety requirements.

3. The Design Specification and Operator's Requirements

3.1. THE DESIGN SPECIFICATION

Of great importance to flight safety is the task of matching the design specification with the operator's, airworthiness and design safety requirements. The operator, being the customer, knows what he wants and does not always appreciate the extent to which he ties down the constructor.

The design specification is the main reference against which the aircraft is assessed under representative operating conditions. The contents are normally agreed before signing the contract. Thereafter, the responsibility of meeting it rests with the constructor. This specification means precisely what it says and failure to meet the standards by as little as one per cent can result in penalty payments under guarantee.

Typical items, many of which have to be demonstrated by the constructor, include the following: —

(*a*) level flight speeds at declared weights to meet a guaranteed range with a tolerance of 3 per cent,

(*b*) take-off and landing distances with related climb requirements over a range of altitudes and temperatures with tolerances of approximately 500 ft. on field length,

(*c*) noise levels, structural weights, with small tolerances associated with an aircraft which is stable about all axes within defined test conditions.

3.2. THE OPERATOR'S REQUIREMENTS

Apart from the design specification each operator as he becomes a customer quite rightly states his own individual requirements. As we all know, these differ quite considerably from one operator to another and

merely complete the jigsaw puzzle of fitting the design to the requirements of each operator while bearing in mind all the time the airworthiness and flight safety requirements.

4. Airworthiness and Design Safety Requirements

4.1. AIRWORTHINESS REQUIREMENTS

As mentioned earlier an aircraft should be designed around the safety requirements to ensure flight safety. In the case of a new type of aircraft airworthiness requirements do not always exist, or are not suitable for the new design. It can be disastrously expensive and unsatisfactory to modify aircraft to meet requirements introduced after the design is well under way. Until recently, we have been fortunate in that a broad code of airworthiness requirements existed before design and construction commenced and the governments or their agencies assumed the responsibility for determining the level of risk acceptable both for those flying and the community in general.

This is a problem which I believe requires urgent consideration, as it is simply a question of whether for new types of aircraft we are going to design the aircraft and fit the requirement to it or, formulate some requirements and then design and test the aircraft to prove compliance. The one thing we should not do is to regard airworthiness as merely a formalisation of some aspects of design irrespective of whether the flight safety has been proved.

The ideal would be to delay airworthiness decisions until sufficient experience has been gained with a new type of aircraft to enable suitable requirements to be formulated. This assumes that the aircraft has demonstrated its airworthiness. As the time factor does not allow this, the airworthiness engineer has to strive to foresee all eventualities associated with a new design and its operating characteristics without direct operating experience.

Finally, on the subject of airworthiness requirements a new problem has arisen in that new designs tend to have different characteristics which cannot be covered adequately by a common code.

4.2. DESIGN SAFETY REQUIREMENTS

Quite apart from the airworthiness code applicable to any type of aircraft, I think it worth while spending a little time reviewing the most important items which must be considered by the constructor under the heading of design safety.

4.2.1. *Performance*

The problem here is to produce an aircraft which gives a satisfactory performance to operators and which, at the same time, has an adequate safety margin to ensure that the take-off, initial climb, *en-route* climb, cruise, descent, final approach and landing will at all times enable the aircraft to be operated safely within certain well defined limits. This of course includes conditions with one or two power unit failures. Much of this can be done by calculation but in the end it has to be demonstrated on an actual aircraft before delivery to the operators. Also, as part of design safety adequate data has to be supplied so that the airline crew has at all times all the information they need to operate the aircraft safely.

4.2.2. *Handling*

If an aircraft, in the opinion of the pilots, handles nicely under all conditions of flight then a great measure of safety has been built into the design. Apart from this, however, much time has to be spent in demonstrating certain essential handling features and, as an example, in the U.K. some 150 items have to be covered during Certificate of Airworthiness flight tests of a transport aircraft. Associated with the handling qualities of an aircraft is the need to design a really good flight deck layout which is satisfactory under all normal and emergency conditions.

4.2.3. *Power plant suitability and reliability*

So long as an aircraft carries fuel there will be a risk of fire and while engines continue to have rotating parts the chances of mechanical failure will be ever present. A great amount of care has to be exercised in the detail design of the power plants to ensure reliability and a low risk of fire. Even then, adequate fire detection and extinguishing systems have to be installed. Also the satisfactory operation of the power units has to be determined under all extreme operating conditions.

4.2.4. *Structures*

To design a light structure for a pressurised aircraft which has an adequate margin of strength under all conditions of operation and freedom from fatigue is a subject which requires the greatest care. The introduction of highly pressurised aircraft has introduced new problems of fatigue. Demonstrating that the safety has been achieved requires very lengthy and expensive ground tests which must, wherever possible, represent operating conditions.

Only time will tell whether the latest "fail safe" British designs which have been thoroughly tested on the ground have introduced a safety margin which we hope will be a good reward for all the efforts which have been put into this design safety feature.

4.2.5. *Systems*

With the ever increasing complexity of aircraft systems the need to ensure complete reliability places a heavy burden of testing on the aircraft constructors. Most systems are tested in the laboratory before the full scale test in the prototype aircraft. The ease of maintenance of these systems is part of the design safety.

5. Proof of Design Safety

5.1. GENERAL

Even if maximum attention has been given in the design office to design safety we are always faced with the problem of proving that this has in fact been achieved. Nowadays, the time and cost factor in producing a new type of aircraft limits the scope of the constructor and the operator is anxious to start passenger service as soon as possible after delivery. The following is a brief survey of the constructor's contribution towards proving design safety.

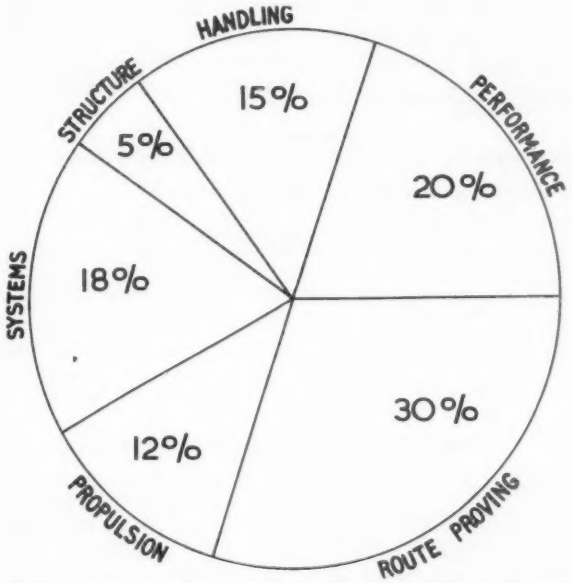

FIGURE 1. Britannia 100 C. of A. flight tests. Proportion of time spent on main groups.

5.2. CALCULATIONS

Calculations form the foundation to all evidence required to prove design safety. They are, of course, far from complete and their value depends so much on the many assumptions which have to be made.

5.3. GROUND TESTS

Most of the basic testing of equipment and systems takes place on ground rigs. The advantage of laboratory control simplifies the accumulation of experimental evidence but the maximum benefit to ensure flight safety can only be gained when the proper conditions of flight are reproduced on the ground rigs and this presents a major problem.

It could be said that pre-operational flying is too short to show, other than to a limited extent, troubles which will occur in service. This leads us to attack the problem much earlier than even laboratory testing by the selection of equipment and components with a background of service in other aircraft followed by detail care concerning their correct installation.

One thing is quite obvious that, on a basis of cost, it is cheaper to submit the component parts of the aircraft to rigorous ground tests in their correct environment so that the final approval certificate can relate equipment to very exacting standards, than to rely on flight test experience.

TABLE I.

BRITANNIA 100 C. OF A. FLIGHT TESTS

Main Group	*Individual Items Checked*
Performance	30
Handling	146
Structural Strain Gauging	72
Pressurisation	15
De-Icing	13
Fuel	36
Auto-Pilot	64
Electrical	45
Radio	40
Power Plant Propeller Strain Gauging	50
TOTAL	511

5.4. FLIGHT TESTS

Flight development of a civil aircraft contributes a great deal towards safety if the process is carefully controlled and the information which is obtained is used properly by the design office. There should be no question of ignoring the results of flight development or trying to find a short cut in completing this phase of the development. It has as its main objectives:—

(*a*) demonstrating the design specification is met,
(*b*) proving compliance with airworthiness and design safety requirements and providing data for documentation such as flight manuals,
(*c*) establishing reliability of the aircraft and its equipment and checking ease of maintenance.

To get a clear picture of this subject I would like to make a brief reference to the scope of flight testing, to prove design safety, which was covered before delivery of the first Bristol Britannia.

Table 1 shows the number of individual items that were checked and fully reported for C. of A. purposes only. The figures denote the number of items and not the number of checks or tests. This is of particular significance in relation to the thirty items of performance as these tests normally occupy the largest number of flying hours other than the endurance flying. Fig. 1 shows the proportion of time spent under the broad headings for *C. of A. tests only*.

Figure 2 illustrates the flying hours carried out on the four aircraft used for C. of A. tests. For the Britannia 100 Series (short range version) almost 1,000 flying hours were used for airworthiness tests out of a total of 2,300 hours which was flown before the issue of the Certificate of Airworthiness. Fig. 3 shows how the four aircraft were used for the various tests and I have chosen it for comparison with Fig. 4 which shows my recommendations for the future.

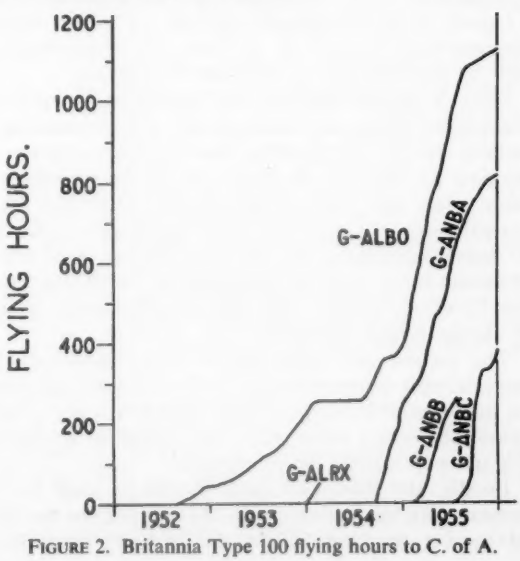

FIGURE 2. Britannia Type 100 flying hours to C. of A.

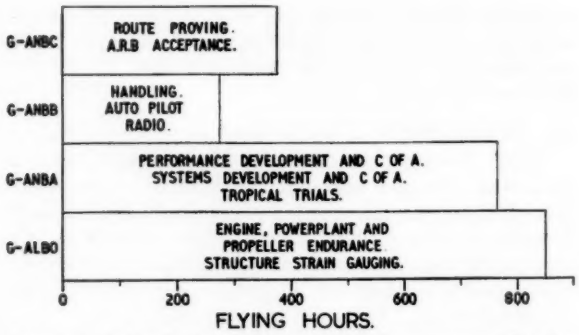

FIGURE 3. Britannia intensive development programme, October 1954 to C. of A. December 1955.

5.5. ENDURANCE TESTS

The problem of proving, before delivery, that an aircraft will achieve a high standard of reliability and freedom from accidents in service is one of the most difficult that the designer has to face. Development brings to light only some of the more malignant snags, while the so-called route proving period of between 100 to 200 hours may be no more than a symbolic gesture towards trouble shooting. While it is generally true that the rate of occurrence of defects diminishes with time, the settling down period may take tens of thousands of flying hours. A satisfactory solution requires urgent consideration from all concerned.

I believe a great contribution can be made towards improving the flight safety of an aircraft by giving further thought to the question of endurance tests under fully representative conditions. I suggest that agreement be reached with all concerned that the amount of flying should be in accordance with the pattern on Fig. 4.

This figure shows flying for a new type of aircraft begun by an engine flying test bed. The engine constructor should no longer be allowed to regard the prototype aircraft as a flying test bed. He should obtain all the essential characteristics of the new engine from a flying test bed and should carry out as many as possible of the C. of A. tests for the particular type of engine including icing conditions. For the engine flying test bed I suggest no less than 450 hours flying at a rate of 50 hours per month, for 9 months.

Next, I suggest that the first prototype be used for development flying only and by this I mean making it available to the constructor for the sole purpose of obtaining all the data required by the design office to satisfy itself that the actual aircraft meets the basic requirements. For this aircraft I suggest approximately 630 hours flying before C. of A. at the rate of 30 hours per month for 21 months, followed by 300 hours flying after C. of A. to deal with those modifications which are always found necessary.

The second prototype should be ready for flight, complete with instrumentation, 4 to 5 months after the first and should be used exclusively for C. of A. tests amounting to not more than 750 hours at a rate of 50 hours per month, for 15 months.

Finally, the third prototype should be used for an operator with the assistance of the constructor for hire and reward carrying freight under strict operational

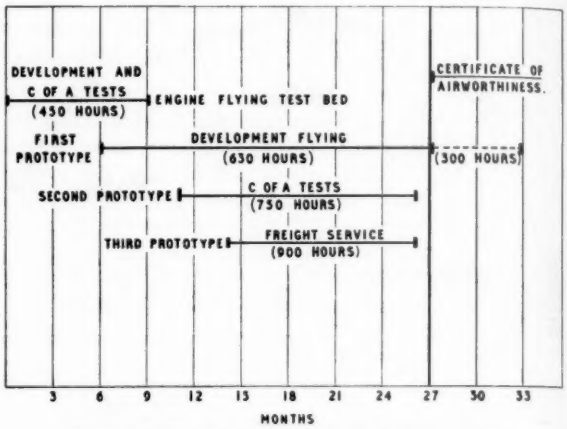

FIGURE 4. Civil aircraft flight tests before service.

conditions. I suggest 900 hours flying at a rate of 75 hours per month, for one year. There is no substitute for operating an aircraft under strict operational conditions which in this case must include all climates and all seasons of the year. In my opinion, the lack of evidence from this type of flying before C. of A. has been a serious missing link in the past which is required to ensure flight safety and reliability.

6. Operational Reliability and Safety

6.1. INCIDENTS AND ACCIDENTS

I believe that if we take the trouble to analyse the records of all operations of, say, post-war British civil aircraft, we should come to one clear conclusion, namely, that for flight safety incidents are not less important but *more* important than accidents. This is due to the fact that the majority of accidents can be traced back to a series of incidents, each one of which was not important in itself but collectively they caused an accident. The following is a typical example:—

(*a*) The flight crew, although rested, did not sleep during the hours of darkness in the country from which they began the flight,
(*b*) during the flight the captain felt unwell,
(*c*) during maintenance of the aircraft before the flight a small item of equipment had been inadequately maintained, as the design made such operation difficult and the maintenance engineer was not feeling well, and
(*d*) during the flight the item of equipment malfunctioned and the captain, due to his state of health and poor flight deck layout, carried out the wrong procedure. A major emergency arose and the aircraft forced landed.

Each one of these incidents by themselves was of little significance but collectively caused an accident. There is much the constructor can learn from incidents.

6.2. THE CONSTRUCTOR'S PART IN AIRLINE OPERATION

The constructor of an aircraft, while having no part in the actual operation other than assistance with technical information and maintenance as required, should take every opportunity of comparing the record of

operation with the experience he gained during the pre C. of A. flying. Constructors should, if possible, be in a position to loan members of their staff to an operator to obtain practical experience for future designs.

6.3. A FEED-BACK OF INFORMATION FROM THE OPERATOR TO THE CONSTRUCTOR

The majority of operators are most helpful with the supply of information concerning the operation of their aircraft. The constructor, however, is faced with the difficulty of analysing all this information and making it available in a suitable form to his staff so that the maximum use can be made of it for both modification and future design work.

6.4. MODIFICATION OF AIRCRAFT IN SERVICE

An important aspect towards flight safety is the modification of aircraft in service. While it is necessary for the constructor to be responsible for major modifications there is some justification from the financial aspect for him to watch most carefully the extent of his contribution. One thing is clear: there should be a complete understanding between the constructor and operator as to the best procedure to be adopted for introducing essential modifications effecting flight safety.

7. Summary and Conclusions

I have tried to outline the constructor's problems in his endeavour to produce aircraft which will have a good "Flight Safety" record. If we wish to see a real expansion in public transport by air, in British aircraft, then we have to start now by giving the maximum attention to flight safety of aircraft of all types. I believe this to be far more important than improving the speed and performance of an aircraft. I am far from being convinced that the majority of airline passengers really want to fly so much faster than the latest types which are now in service. We must resist the temptation of allowing the increase in speed in aircraft to reduce the overall flight safety. It is high time we were producing and operating aircraft of the fixed and rotating wing type which by virtue of their known safety record are accepted by the travelling public as an everyday means of transport. We must achieve a situation where the average passenger no longer exhibits fear concerning his safety during flight. The constructor's contribution to this can only be achieved if he treats the subject very seriously and makes full use of all the experience obtained by the operators.

Acknowledgment

I am indebted to Bristol Aircraft Ltd. for permission to give this paper. The opinions expressed are my own.

Summary of the Discussion

by

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THE OPERATOR'S AND THE PILOT'S VIEWS

The Chairman, introducing the discussion, summed up the philosophies of the first two speakers. Captain James had postulated that in no human activity could safety be absolute, and that in aviation the limit to safety was set partly by economic factors and partly by other considerations such as human fallibility. On the other hand, Captain Miles believed that safety should not be a negotiable quantity. Further points worth underlining were the apparent constancy of the human error factor, the need for the maximum circulation of information, and the value of continued research and development in the landing and take-off phases and in Air Traffic Control procedures and organisation.

The discussion was then opened by a speaker from the Air Registration Board who emphasised the difficulty of setting fair standards for operators of new aircraft which did not impose excessive economic penalties. He also suggested that more use be made of simulators to practise emergencies which it was unwise to simulate during flight; but if it was considered dangerous to practice flight at *Vmc* for instance, then the aircraft should obviously not have been certificated with that value of *Vmc*. Captain Miles' remarks supported the discriminate use of statistics but he emphasised that they were not a sound substitute for measurable operational parameters. The passenger-mile criterion might be very misleading when comparing safety levels of different forms of transport, aircraft with taxis, for example, and it was suggested that passenger-hours would be a better basis of comparison.

Captain James said that, in the setting of standards, the operator himself was primarily responsible. He thought it would be a pity if there was so much legislation that no initiative was left for the operator. Regulations should only be concerned with the establishment of the lower limits. He did not disagree that all reasonable emergency manoeuvres should be able to be practised in flight, but considered that there was much more benefit from reproducing the emergency conditions in a simulator.

It was suggested that flying ought to be as safe as sitting in an office. Captain Miles agreed; the cockpit *was* the pilot's office. Explaining his thesis that all foreseeable accidents must be prevented, he mentioned ground stall, fatigue and altimeter misreading as examples of causes of foreseeable accidents, whereas human error was unforeseeable.

A representative of the Air Ministry Directorate of Flight Safety discussed the differences between civil and military philosophies of safety. There was a much finer balance, on the service side, between operational safety and their equivalent of profit-making, which was national safety. They had had a steady reduction in both technical and human causes of accidents, but the rate due to human error was improving more rapidly. Many apparent air crew

errors actually originated in concealed technical faults; misjudgment of an asymmetric approach, for instance, might well be considered as due to features inherent in the design. In the field of co-operative flight safety effort, this speaker deplored the lack of any U.K. organisation comparable to the New York Flight Safety Foundation. He strongly urged the establishment of a responsible authority in the U.K., but added that the Flight Safety Foundation lacked the requisite impartiality to be adopted as the parent of an international organisation.

A member of Hawker Siddeley's Advanced Project Group was mainly concerned with the reliability of systems, and maintained that no equipment could have zero probability of failure. The probability approach, calculated theoretically but with an applied factor based on a statistical analysis of actual failures, was a convenient yardstick of safety. It was interesting that the probability of human failure was relatively constant. The advantage of the human in a system was his ability to take decisions, particularly when there was some equipment failure, but his long response time was a drawback. Simulator test programmes should include failure cases, during which the crew should be subjected to realistic physiological and psychological stresses. He emphasised the importance of the new subject of human engineering in this context. Existing techniques did not take these factors into account, and information was urgently required by designers. More details of actual failures were needed, to be fed back into the design.

Captain Miles agreed that equipment failure probability could never be zero, but maintained that the probability of failure of the overall situation could achieve zero. In the example of an engine failure on take-off, the certificated take-off distance was multiplied by 1·15 to give the flight manual distance, with an associated probability that this distance would be exceeded once in, say, 100,000 times. No such factor was applied to the one engine inoperative distance. But by increasing the runway length sufficiently, the most adverse combination of failures foreseeable would not result in disaster. This was an example of what he meant by the overall probability of failure being zero.

A warning that the probability concept could be misleading was given by a representative of Bristol Siddeley Engines Ltd. He told the story of a man who thought he would be safer if he stayed in bed all his life, but who was then disappointed to hear that more deaths occurred in bed than anywhere else. In all forms of human activity some risk was accepted for a certain return. No doubt safety in air transport could be greatly improved, but not without paying the penalties of a reduction in its volume and efficiency.

The operation of supersonic aircraft would present many unknown problems, particularly the choice of an acceptable balance between safety and economy. There was still far too little co-operation between the constructors and operators on this point.

It was suggested that there were differences in the standards of large and small operating companies. Captain James agreed that this was usually so; since the public reaction to an accident was the same regardless of the size of the operator's fleet involved, the larger operator must have a higher standard to keep the same reputation.

A member of the B.E.A. engineering staff said that the biggest single factor to be considered was the rate of technological change. The stage had now been reached at which the possibility of human error outside the cockpit was more important than it was inside the cockpit.

Another representative of the A.R.B. disagreed with Captain James on the use of simulators to test aircraft behaviour in emergency conditions. Simulators did not reproduce aircraft characteristics with sufficient accuracy for this purpose, and there was the further uncertainty as to how a pilot would react. He agreed that incidents would provide valuable information; but pilots were reluctant to report them because of professional pride.

In reply, Captain James said that this reluctance of pilots to report incidents was a problem of management. He suggested that it could be overcome by setting up an independent body, having no connection with the executives, to which pilots could report without fear of being penalised. Captain Miles spoke of the realism with which emergencies could be reproduced in simulators, and emphasised that their main value was to give practise in emergency procedures. It was not yet possible to predict whether they could be developed as a means of proving aircraft behaviour.

There was some discussion of airline approach techniques. Even in cases when the runway length was not critical, pilots frequently dropped below the ILS glide-path on the final stages of the approach, thereby increasing the probability of undershoot accidents. Captain Miles suggested this tendency had arisen because certificated landing distances were unrealistic. During certification trials there was a desire to minimise the landing distance by using lower speeds, higher rates of descent at touch-down, and severe braking on dry concrete runways. The certificated landing distance should now be based on the standard glide-path and a more representative airline technique.

THE ACCIDENT INVESTIGATOR'S AND CONSTRUCTOR'S VIEWS

An ex-R.F.C. pilot said that modern aircraft seemed much more likely to burn after a crash than did aircraft in 1914-18. Mr. Tweedie agreed, but the circumstances were very different. Although fire suppression was relatively easy in flight, it was extremely difficult following a crash. About the only occasions when a major fire could not occur were those in which the aircraft disintegrated over a sufficiently wide area.

The system of concessions used by large concerns with sub-contractors was criticised. It was suggested that there was a risk of misinterpretation of concessions which could be aggravated by the inevitable administrative delays and associated paperwork. Any consequent wrong application of these concessions could have disastrous effects. Mr. Warde did not consider that the present system of concessions gave cause for concern since they were restricted to small quantities. Most subcontractors had their own A.R.B.-approved inspection organisation.

It was suggested that more aircraft should be available than were made use of in the flight testing scheme proposed by Mr. Warde, and that modification testing should be done before instead of after the C. of A. was granted. To the first criticism Mr. Warde replied that the number of aircraft available for development and certification trials was limited by time and money and that the cost of modifications would increase with the number of aircraft being modified. He agreed that it was desirable, although not essential, to prove any modifications before the C. of A.

A speaker from Vickers-Armstrongs described the extensive experience his Company had had in building up relations with the many operators of their aircraft. The larger operators were particularly co-operative in reporting engineering defects. He considered that the state-of-the-art in fatigue was such that all incidents due to this cause should now be classified as foreseeable.

The need for crash-recorders, stressed in Mr. Tweedie's paper, was discussed at some length. A representative of the Ministry of Aviation asked if there was any requirement for a continuous monitoring recorder. Mr. Tweedie answered that, for his purpose, a continuous recorder was not suitable; all he wanted was a simple recorder with perhaps an hour's memory taking not more than about six parameters and for which the three essential qualities were simplicity, strength and recoverability. He was not prepared at that time to specify the six most important parameters, but tentatively suggested altitude, air speed, heading and power output as among those that might be selected. Captain James said that the need for a continuous recorder was a very controversial issue, and depended entirely on the value of the information it provided.

Captain Miles said that although pilots were suspicious of their employers they supported the fitting of continuous recording equipment, provided it was only used in accident investigation—and not by the employer. The simplest of all crash recorders was described by Mr. Tweedie as a fireproof brick having a number of holes drilled through it, each indicating a possible cause of failure. The holes were blanked off by means of a fireproof membrane. If the pilot found himself in trouble he merely inserted a finger in the appropriate hole and broke the membrane!

On the subject of colour codes as a means of identification, Mr. Tweedie said that his investigators always had made use of whatever differences in pattern or colour, if any, *happened* to be available on any part of an aircraft. The idea of a *planned* colour code began to crystallise during the investigation of helicopter blade failures. He did not think there should be any difficulty in suitably colouring the internal structure of an aircraft during its construction.

A Handley Page design engineer admitted that designers might be ignorant of the operator's requirements, but blamed the operator for not making these clear. He said that safety had to be incorporated during the design stage, not afterwards. It had to be decided to what extent consequential and multiple failures should be covered; the more elaborate the safety precautions, the less economically competitive the design became.

The importance of the dissemination of safety information to the lowest level was pointed out by a technician from Boscombe Down. His experience in checking installations for failure cases showed that vital information was often withheld from the junior draughtsmen responsible for the detail design. He urged that all design work be tackled with a more critical outlook from the beginning.

The Ministry of Aviation was criticised for its inability to produce any adequate flight safety publications. Several journals in the U.S. presented both detailed accident reports and examples of typical design faults, whereas the only relevant British publication was the Ministry's annual list of the accidents to civil aircraft in which all details were intentionally omitted. Mr. Tweedie said that full accident reports were in fact released by the Ministry, and also mentioned the annual I.C.A.O. digest of accidents to public transport aircraft throughout the world. The Chairman remarked that unfortunately no representative of the aeronautical press seemed to be present to defend their case.

A B.E.A. engineer said that in a previous Society lecture he had offered to accept members of design staffs in the industry for temporary positions with his engineering staff, in an attempt to facilitate the exchange of ideas and experience, but that there had been no response at all. He also pointed out that whenever a course on a new aircraft was held, the appropriate manuals were never ready; personnel thus got into the habit of referring to their instructors' notes which were inadequate for the purpose.

GENERAL DISCUSSION

The Chairman opened by considering the possibilities of improvement. The human factor was the predominant cause of failure whether in design, construction, development, maintenance or operation. Efficient training of personnel seemed to be the key to raising the standards. Human failure in the cockpit was perhaps the most difficult.

Captain James discussed the problem of the introduction of a new type to airline operation. But crews and engineers were invariably at their most alert when operating a new type, or a new route, and it was when they had become familiar with their job that complacency and negligence usually arose. Tuning into the wrong beacon, misreading an instrument or even landing at the wrong airfield were the sort of errors that occurred under these conditions. It was a statistical fact that every professional pilot would make one serious mistake during his career. By having one pilot to monitor the other at all times during the flight, and particularly at the critical stages such as landing and take-off, this inevitable error was prevented from having any serious consequences. This led to the philosophy of "aeroplane management," *i.e.* that there should be one crew member, the captain, whose sole responsibility was to manage, or monitor the other crew members, and who had no other functions to perform.

An officer of the Directorate of Flight Safety, of the former Air Ministry, described the procedure for Special Occurrence Reporting, and urged that the information obtained be used vigorously and intelligently.

A representative of aviation insurance suggested the use of a new term: *Variact* (=Variation from Optimum), to replace *error,* which carried an undesirable emotional charge. He criticised the attitude of those responsible for making regulations, which, he said, seemed to be "find out what Johnny is doing and we'll stop him." He proposed the establishment of Flight Safety Authorities, to be responsible for (*a*) the training and indoctrination of the appropriate staff, (*b*) the investigation of all accidents and incidents and (*c*) the implementation of its findings. The creation of a Flight Safety Authority within each organisation should become statutory, he considered, and should be the logical outcome of the deliberations of the existing Transport Flight Safety Committee.

The practical motivation of a flight safety programme was described by another member of the Directorate of Flight Safety. Such a programme had been carried out by the R.A.F. some years ago and showed that the accident trend of a new type decreased exponentially with time (known as the Bevan Law), but that this trend could be decreased at a greater rate by the correct preventative action. An aircraft type which had been in service for a considerable time was thus relatively safer than a more recent type. The DC-3 was the supreme example of a "safe" aircraft in this sense. The preventative action consisted of (*a*) remedial action following careful analysis of accidents and special occurrences, and (*b*) control to ensure that lessons learnt were not forgotten. The Chairman thought that there would not be enough accident statistics to motivate a similar flight safety programme in British civil aviation.

A speaker from Boscombe Down gave some examples of dangerous design faults which had been discovered subsequent to clearance by the constructor; the proximity of fuel drains and vents to air intakes, a pump failure light downstream of the accumulator system, and the fitting of two pumps but with no indication of failure. These typical cases showed the importance of initiating remedial action in a programme as early as possible. A badly positioned fuel vent had in fact been brought to the designers' attention two years before a fire occurred from that cause! A representative of the Guggenheim Aviation Safety Center appealed for a much wider exchange of information between organisations on an international scale.

The Symposium was closed with a summing-up by the Chairman. There had been discussion of the probability approach, and various views had been presented as to what was an acceptable safety level. Some had said that the existing level should be maintained, others that an improvement was essential, or even that it should be ten times better. The emphasis was on human failure as the original cause of accidents, whether in the design office, in the cockpit or elsewhere. Many ways of raising the standard of safety had been indicated; the exchange of information could certainly be improved at all levels and in all directions, and information on incidents was much needed. Mr. Tweedie had suggested how the accident investigator's task could be made easier. Many individual seeds of thought had been sown, such as the proposal that flight safety authorities be set up within firms and operating companies. Finally he thanked the lecturers and audience for their part in the Symposium. Captain James, on behalf of the lecturers, expressed their thanks to the Chairman for his capable and fair handling of this vital but highly controversial subject.

TECHNICAL NOTES

Note on Some Applications of the Matrix Force Method of Structural Analysis

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1. INTRODUCTION

The Matrix Force Method is frequently used in the stress analysis of complicated aircraft structures. It assumes as unknown quantities, or redundancies, groups of internal loads, and yields stresses and displacements in terms of a set of unit loads. Lately, this method has been extended to include effects of uneven temperature distribution. With large structures, the method is most effective with high speed digital techniques which allow considerable computational detail to be stored in the computer memory. Theoretically, the method is based on the Castigliano theorem of least work, equivalent formulations being possible. Hence the method is applicable to elastic problems of the first order only, *i.e.* strains infinitesimal, structural distortions not affecting equilibrium conditions markedly.

In the technical literature, by far the most important contribution to the Matrix Force Method is a series of papers by Professor Argyris in "Aircraft Engineering" and their summary in A.R.C. R. & M. 3034[1, 2]. There the method is extended to problems of cut-outs and other structural modifications, thus providing means, of great practical importance, to account for small changes in design without necessity of doing the computation all over again. During his employment with Avro Aircraft (Canada) Ltd. the author has used the method extensively for many years and published recently[3] a contribution to certain practical computational aspects. Computations were on quite a large scale and also included thermo-stress and cut-out problems.

The Matrix Force Method, being a technical analysis, depends for success on skilful simplification of a problem. Since structural forms evolve continuously, care should be taken to have the method constantly amended as simplifications justified for a certain type of structure may not be admissible for a modified one. The main simplification usually taken is known as the procedure of lumping the direct stress carrying structural material along the intersection lines of the shear carrying sheets, panels, webs, or whatever names are chosen to identify these elements. Although unavoidable in most applications, lumping should not be used with two- or three-spar wings as, in this case, over-estimation of the strain energy of the internal warping groups may lead to an inaccurate result. Ref. 3 provides an indication of how to get around this difficulty.

An important value of the Matrix Force Method lies in its ability to determine perturbations in a stress distribution due to uneven heating, cut-outs and other structural modifications without a necessity of repeating the computation *ab initio*. However, the method propounded in Ref. 1, which introduces a concept of "initial strain", appears to be an over-simplification not generally admissible. Specifically, the simplification appears to be limited to structures for which the flexibility matrix is, or can be assumed, mostly diagonal, while for structures exhibiting a more densely populated flexibility matrix, as swept low aspect ratio wings for instance, a different concept should be used.

The author's purpose here is to discuss the general case of a structure for which the flexibility matrix is not only diagonal. The brevity of the adopted treatment may imply an undue criticism of Ref. 1 which is not intended, and for which the author may owe an apology. However, the manner of proceeding is dictated by two circumstances: first, Ref. 1 is very complete indeed, so that if a new paper were written, it would consist for the most part of repetitions; and, secondly, a reference has been made recently to it in the AGARD report of Professor Argyris[2], and in the ensuing discussion at the AGARD symposium on digital methods in Aachen, September 1959. By selecting this publication as a basis for discussion, no objection is made to the validity of formulae contained in the text, providing that they are used with the numerical examples of the text. The point of discussion concerns the concept of the initial strain introduced in connection with the thermo-stress, and cut-out techniques, which concept, as will be shown below, should not be extended to structures, such as low aspect ratio swept wings, where a strong coupling exists between various stress components in the flexibility matrix.

In the text which follows, symbols and notations of Ref. 1 are used whenever possible.

NOTATION

NOTATION OF REF. 1

b	matrix, relating stress to the applied load, general
b_0	matrix, relating statically determined stress to the applied load
b_1	matrix, relating stress to the redundant internal load
F	matrix, relating displacement to the applied load
f	matrix, relating strain to stress
H	column, generalised initial strain
h	index, denoting the cut-out elements
g	index, denoting the remaining elements
I	unit matrix
R	column, applied load
r	column, displacement
S	column, stress
X	column, redundant load
θ	column, temperature
prime ($'$)	indicates the transpose matrix

NOTATION OF REF. 4

α	coefficient of thermal expansion
E	Young's modulus of elasticity
ν	Poisson's ratio
σ	stress
x, y	co-ordinates
X, Y	fictitious thermal loads
θ	temperature

Received January 1960.

ADDITIONAL NOTATION IN THIS NOTE

α numerical factor introduced by [7]
G applied load in terms of shear flow
k ratio $\Delta t/t$, also a diagonal matrix of cross-sectional changes
Q index, denoting relation to the applied load
T panel shear flow
t thickness
θ index, denoting relation to temperature

REFERENCE TO FORMULAE

Formulae of Ref. 1 in round brackets, *e.g.* (38)
Formulae of this note in square brackets, *e.g.* [17]

2. THERMAL STRESS ANALYSIS

The thermal problem is discussed at the end of Part I of Ref. 1. In paragraph 7 the authors have established the compatibility equation (38):—

$$b_1'fb_0R+b_1'fb_1X=0$$

the true stress matrix (41):—

$$S=(b_0-b_1D^{-1}b_1'fb_0)\,R=bR$$

and the overall flexibility matrix (43):—

$$F=b_0'fb$$

Then, in paragraph 8, instead of using (38) for derivation of thermo-stresses and displacements, they proceeded with a new compatibility equation in terms of strain (47)

$$b_1'H+b_1'fb_1X_H=0\ .$$

This is a simplification which should not be used with swept low aspect ratio wing structures.

The theory of thermal stress and displacement is elaborated in Ref. 4, para. 137, pp. 421-425 and in para. 140, pp. 434-435. Accordingly, thermal displacements are such as though "fictitious thermal loads" of the magnitude

$$X=-\frac{\alpha E}{1-\nu}\frac{\partial\theta}{\partial x},\quad Y=-\frac{\alpha E}{1-\nu}\frac{\partial\theta}{\partial y}\quad .\quad .\quad [1]$$

were applied to the structure; but stresses resulting from these fictitious loads have to be modified by the quantity

$$\sigma_x=\sigma_y=-\frac{\alpha E\theta}{1-\nu}\quad .\quad .\quad .\quad .\quad [2]$$

in order to represent true thermal stresses.

When translating this concept to a problem in formulation of the Matrix Force Method, one can see at once that the fictitious thermal loads themselves, or their static equivalents, are not required at all since what we need is merely their contribution to the basic statically determinate stress system. This contribution is, in the case of a non-swept wing, exactly the column,

$$\frac{\alpha E\theta}{1-\nu}\quad .\quad .\quad .\quad .\quad .\quad [3]$$

relating stress of the spar and rib flanges, or caps, to temperature at the nodal points. In the light of the theory of Ref. 4, the only place where one can make use of this column is equation (38). There, it replaces the column b_0R. In matrix formulation, the column is factored into a matrix $b_{0\theta}$ with elements equal to $\alpha E/(1-\nu)$ or zero, and into a column of temperatures θ. Thus the thermo-stress is given by the formula

$$S=(b_{0\theta}-b_1D^{-1}b_1'fb_{0\theta})\,\theta-b_{0\theta}\theta\quad .\quad .\quad [4]$$

$$=-b_1D^{-1}b_1'fb_{0\theta}\theta=b_\theta\theta\quad .\quad .\quad [5]$$

and the thermal displacement is given by

$$r_\theta=F_\theta\theta=b_0'f\,(b_{0\theta}+b_\theta)\,\theta\quad .\quad .\quad [6]$$

in agreement with formulae (12h) and (12i) of Ref. 3. In swept wings the matrix $b_{0\theta}$ will include panel terms as well, *see* Ref. 3, Fig. 10.

It appears on examination that when f is a diagonal matrix, formulae [5] and [6] reduce to (49) and (50) of Ref. 1, since then $H=fb_{0\theta}\theta$.

3. CUT-OUT PROCEDURE

The problem of a structure with cut-outs is discussed in Part II of Ref. 1. It is stated in the opening paragraph 9 as follows: "To preserve the pattern of matrices and equations disturbed by missing shear panels and flanges, we fill in the cut-outs by introducing fictitious shear panels and flanges with arbitrary thicknesses or cross-sectional areas. . . . . To obtain, nevertheless, the same flange loads or shear flows in our continuous structure as in the original system, initial strains are imposed on the additional elements of such magnitude that their total stress due to both loads and initial strains become zero. The effect of the fictitious elements is thus nullified whilst the uniform pattern of our equations is retained. Let the column matrix of the unknown (generalized) initial strains, imposed on the additional elements only, be H."

In the opinion of the author the physical meaning of the term "initial strain imposed" should be clarified. Two interpretations are possible. One is in assuming that the structure has been pre-stressed in the manner of pre-stressed concrete structures, shrink-fit connections, and so on. In other words, elements to be removed would have had to be manufactured to special predetermined dimensions and then forcedly inserted into the structure. As this would provide zero stress in some desired locations but for one loading condition only, and leave residual stress for the no load condition, this interpretation is ruled out. The other alternative is the assumption that strains to be imposed are generated by an appropriate heating or cooling of the superfluous elements. While one could agree to use this concept in the analysis of structural deformation after yield (the author has made an attempt in this direction) nevertheless, it is difficult to accept it in a purely elastic analysis. For, frankly, the foregoing assumption amounts to admitting existence of a sort of Maxwellian demon alternately blowing hot or cold on the structure in order to keep stress in some elements zero because we want it that way.

On taking a closer look, an entirely rigorous treatment of the cut-out problem is possible. Let Fig. 1 represent a portion of a wing structure from which a panel is intended to be removed. Assume that due to an applied load system Q the panel develops a shear flow T_Q. Evidently the problem could be settled at once by cutting the panel out and by applying a flow $-T$ to the structure as a load and a flow $+T$ to the panel. Then the panel could be removed from

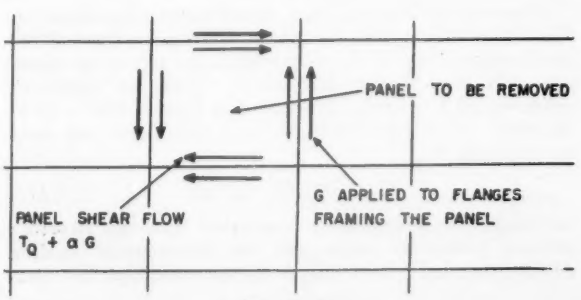

FIGURE 1.

the structure. The difficulty here is that we do not know how to analyse the structure without the panel for a load $-T$. For this is precisely what we wanted to avoid by analysing the structure with the panel. The problem can be circumvented, however, by applying an unknown flow load G to flanges framing the panel. This load generates in the panel the shear flow αG and we know how to compute it. The total panel flow is now

$$T=T_Q+\alpha G. \quad . \quad . \quad . \quad [7]$$

Dependence of T on G is shown in Fig. 2, where, as the panel is confined, α is taken smaller than unity. Thus, if G is increased, a state is reached such that the panel shear flow T equals the applied flow load G. When this happens, the panel can be removed from the structure while carrying the load G with it. After that, the structure is not loaded at the cut-out either by the flow load G or by any panel reaction $-T$. Hence the condition for the magnitude of the cut-out interference G is

$$T_Q+\alpha G=G. \quad . \quad . \quad . \quad [8]$$

This reasoning replaces that of Ref. 1 entirely without resorting to any thermo-elastic concepts. For many cut-outs, say h, the conditioning equation can now be written in a matrix form with help of the equation (41) of Ref. 1. When the Gs are expressed in terms of stress of the elements to be removed, the matrix b_0 for this particular loading is a unit matrix of the order h, denoted subsequently by I_h. The conditioning matrix equation is then, after [8],

$$b_h R+(I_h-b_{1h}D^{-1}b_1'f_h)\,G=G. \quad . \quad [9]$$

After cancelling out we obtain

$$b_{1h}D^{-1}b_1'f_hG=b_hR \quad . \quad . \quad . \quad [10]$$

which substitutes for equation (59) of Ref. 1. The true stress column (60) becomes now

$$S_g=[b_g-b_{1g}D^{-1}b_1'f_h\,(b_{1h}D^{-1}b_1'f_h)^{-1}b_h]\,R \quad [11]$$

since in the range of remaining elements g, all terms of the b_0 matrix for the G-loads are zeros.

It is possible now to recognise where the formulae of Ref. 1 will be correct and where not. They will be correct always when the elements to be cut-out are not coupled with any other elements in the flexibility matrix f. In this case the term of our interpretation f_hG can be taken as the "initial strain to be imposed" H. In the general case, however, in swept wings in particular, the coupling may be quite strong as shown in Ref. 3, Fig. 7.

4. STRUCTURAL MODIFICATIONS

The technique of modifications is introduced in Ref. 1, paragraph 12. Here we meet again the simplifying concept of initial strain. The following reasoning is free from it.

4.1. *Cross-Sections are Increased*

Suppose that the thickness of the panel represented in Fig. 1 is increased from t to $t+\Delta t$. We put a sheet of the panel material but of the thickness Δt on top of the panel still with the original thickness t. Then we apply an unknown load G to the structure and a shear flow $-G$ to the sheet. If G is such that strains in both panel and sheet are the same, *i.e.*

$$(T_Q+\alpha G)/t=-G/\Delta t \quad . \quad . \quad [12]$$

evidently, the sheet can be connected with the structure without additional strain and the hypothetical loading device removed. With $\Delta t/t=k$, the condition for G is

$$G\,(1+\alpha k)=-kT_Q. \quad . \quad . \quad [13]$$

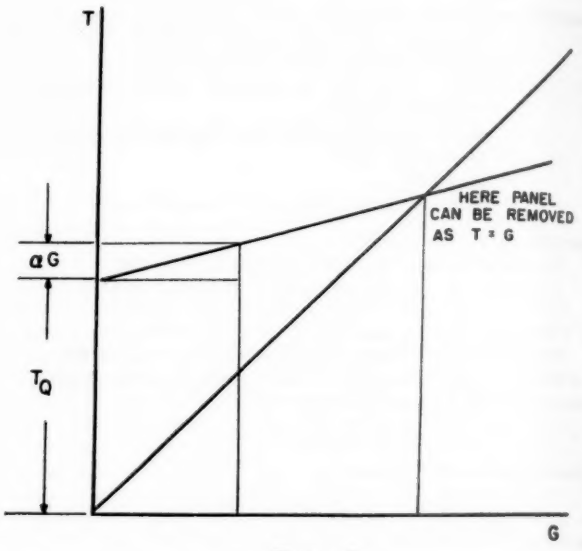

FIGURE 2.

4.2. *Cross-Sections are Decreased*

Suppose that the thickness of the panel of Fig. 1 is decreased from t to $t-\Delta t$. We cut the panel into two parts, one of thickness $t-\Delta t$, the other of thickness Δt, and apply an unknown load G. As the panel of thickness Δt is still connected with the structure, its shear flow can be computed. It is

$$T=(T_Q+\alpha G)\,\Delta t/t. \quad . \quad [14]$$

When the applied shear flow G is such that

$$(T_Q+\alpha G)\,\Delta t/t=G \quad . \quad . \quad . \quad [15]$$

the panel of thickness Δt can be disconnected from the structure, as in the case of cut-outs, and put aside together with the load G. Thus the condition for G is

$$G\,(1-\alpha k)=kT_Q. \quad . \quad . \quad . \quad [16]$$

In the limit $\Delta t=t$ the formula derived for the cut-out case is obtained.

It appears that when in the case 4.2, cross-sections decreasing, k is defined as a negative quantity, equation [16] is of the same form as equation [13]. Thus, if there are h modified elements, some with cross-sections increasing and some decreasing, the conditioning equations can be written in a matrix form. When G is taken in terms of stress, the matrix equation is

$$[I_h+k\,(I_h-b_{1h}D^{-1}b_1'f_h)]\,G=-kb_h\,R \quad . \quad [17]$$

where k is a diagonal matrix of relative cross-sectional changes to the order of h. From equation [17] G is obtained. Accordingly, and considering that in the range g all terms of the b_0 matrix for the G-loads are zeros, the stress system of the modified structure is

$$\left.\begin{aligned} S_g&=b_gR-b_{1g}D^{-1}b_1'f_hG \\ S_h&=-k^{-1}G \end{aligned}\right\} \quad . \quad . \quad [18]$$

as it follows from (41) in presence of [17]. It can be shown that if in some elements k approaches zero, the corresponding S_h approaches b_hG.

It is not possible to ascertain, without going into a numerical computation, whether equations [18] do yield the same result as equations (67)-(70) of Ref. 1. However, as

there is one solution to an elastic problem, both results can not be at the same time true.

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A Note on Shock Detachment Distance

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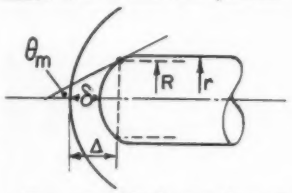
THERE HAVE BEEN numerous attempts to predict the stand-off distance of bow shock waves, ranging from the exact solutions of the inviscid flow equations by Mangler (1959) and Van Dyke (1959) to the semi-empirical treatment of Moeckel (1949) and Love (1957). Sinnott (1959) has recently proposed a single formula $\Delta/R=K\cot\theta_m$ where K is a numerical constant given as 0·77 for axisymmetric bodies and the symbols are defined in Fig. 1.



θ_m = maximum cone semi-angle for an attached shock wave.

FIGURE 1. The equivalent cylinder.

For any Mach number the conical flow detachment angle θ_m is available from tables. A line tangential to the given body surface subtending an angle θ_m with the body axis can be drawn and fixes Δ and R.

In this note the values suggested by Sinnott are compared with other estimates and with experimental data for three types of body shown in Fig. 2. Some comments are made concerning ogival bodies.

FIGURE 2. (*i*) FLAT BODY WITH ROUNDED SHOULDERS

$$\frac{r_s}{r}\leqslant 1;\ \frac{\delta}{r}=\frac{\Delta}{R}\left[1-\frac{r_s}{r}(1-\cos\theta_m)\right]-\frac{r_s}{r}(1-\sin\theta_m) \qquad (1)$$

FIGURE 2. (*ii*) BODY WITH SPHERICAL CAP

$$(a)\quad \psi>\theta_m;\ \frac{\delta}{r}=\frac{\Delta}{R}-\frac{x}{r} \qquad (2a)$$

$$(b)\ \psi<\theta_m;\ \frac{\delta}{r}=\frac{1}{2}\left(\frac{x}{r}+\frac{r}{x}\right)\left[\frac{\Delta}{R}\cos\theta_m-(1-\sin\theta_m)\right] \qquad (2b)$$

FIGURE 2. (*iii*) CONICAL BODY

$$\frac{\delta}{r}=\frac{\Delta}{R}-\cot\theta_n \qquad (3)$$

FIGURE 2. (*iv*) OGIVAL BODY

$$\frac{r_s}{r}\geqslant 1;\ \frac{\delta}{r}=\frac{\Delta}{R}\cdot\left[1-\frac{r_s}{r}(1-\cos\theta_m)\right]-$$
$$-\left[\sqrt{\left(2\frac{r_s}{r}-1\right)}-\frac{r_s}{r}\sin\theta_m\right]. \qquad (4)$$

where $\dfrac{r}{r_s}=1-\cos\theta_n$

Received 24*th February* 1960.

BLUNT BODIES

Data are available over a wide range of Mach number for the two limiting cases of type (*i*) bodies *i.e.* the flat-ended cylinder ($r_s/r=0$) and the hemisphere cylinder or sphere ($r_s/r=1$). The experimental results for the flat-ended cylinder are plotted in Fig. 3(*a*) together with the values suggested by Sinnott and Serbin (1958). The agreement between "theory" and experiment is very good. Fig. 3(*b*) compares the exact values of Mangler and Van Dyke with those of Sinnott and Serbin. Van Dyke has already demonstrated the excellent agreement between experiment and his solution so only some recently published transonic and hypersonic tunnel results are included. Fig. 3 shows that although the success of the simple formula $\Delta/R=0{\cdot}77\cot\theta_m$ varies with body shape, it does predict the stand-off distance to within 10 per cent. Love (1957), who suggested an equation of similar form, used the experimental data to plot K against Mach number. His values ranged from 0·76 to 0·86.

Another check on the suggested formula can be made by testing related body shapes at a constant Mach number. Bodies of type (*i*) were tested in the hypersonic gun tunnel at Imperial College at a Mach number of 6·8. Equation (1) forecasts a linear variation of stand-off distance δ with shoulder radius r_s. Fig. 4 shows that the experimental results agree well with this prediction. Data presented by Lees (1958) is also included. Tests on bodies of type (*ii*) have been reported by Boison and Curtiss (1959) at $M=2{\cdot}01$ and 4·76, and by Lees (1957) at $M=5{\cdot}8$. Again the predicted variation (of equation (2)) agrees well with the experiments (*see* Fig. 5) δ decreasing linearly with x until $\psi=\theta_m$. For $\psi<\theta_m$ the body behaves as a hemisphere.

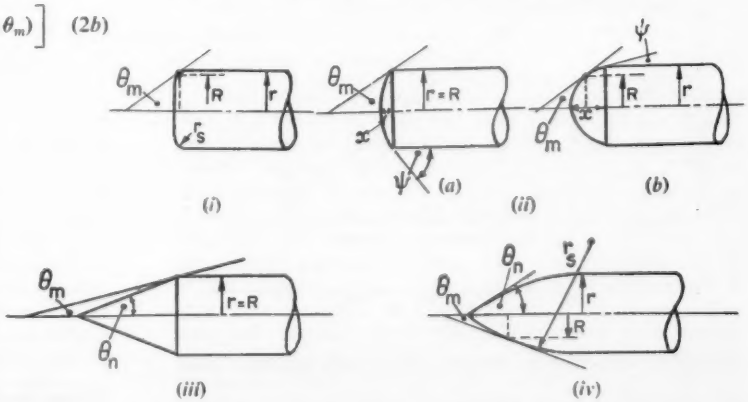


FIGURE 2. Types of body considered.

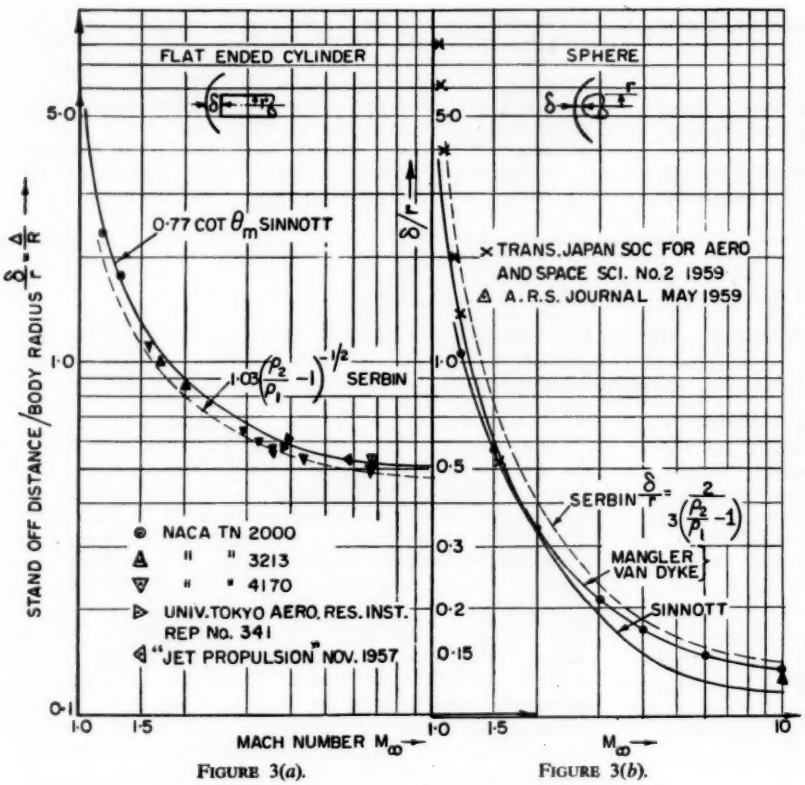

FLAT ENDED CYLINDER
SPHERE
0·77 COT θ_m SINNOTT
$1{\cdot}03\left(\frac{\rho_2}{\rho_1}-1\right)^{1/2}$ SERBIN
× TRANS. JAPAN SOC FOR AERO AND SPACE SCI. NO. 2 1959
△ A.R.S. JOURNAL MAY 1959
SERBIN $\frac{\delta}{r}=\frac{2}{3\left(\frac{\rho_2}{\rho_1}-1\right)}$
MANGLER VAN DYKE
SINNOTT
● NACA TN 2000
▲ " " 3213
▽ " " 4170
▷ UNIV. TOKYO AERO. RES. INST. REP No. 341
◁ "JET PROPULSION" NOV. 1957
STAND OFF DISTANCE/BODY RADIUS $\frac{\delta}{r}=\frac{\Delta}{R}$
MACH NUMBER M_∞
M_∞

FIGURE 3(*a*). FIGURE 3(*b*).

correlated the results of stand-off distance for a number of cones and a single ogive against the transonic similarity parameter $(l/R)(M^2-1)^{1/2}$, where l is the distance from the shoulder to the nose. A straight line can be drawn through most of the experimental points in the range $\delta/\Delta>0{\cdot}2$ to give a relationship $\Delta/R=1{\cdot}5\tan\mu$ where μ is the Mach angle. (There is little difference between $1{\cdot}5\tan\mu$ and $0{\cdot}77\cot\theta_m$ for $1<M<2$.) As the stand-off distance decreases however, $(\delta/\Delta<0{\cdot}2)$ so the relation breaks down. Love (1957) proposed the formula for the stand-off distance on a cone as $\delta/r=\cot\theta_m-\cot\theta_n+y$ where y is a quadratic in θ_m and θ_n. It is interesting to see the regions in which the simple formula suggested by Sinnot is useful for pointed bodies. Fig. 6, taken from N.A.C.A. T.N. 3213, shows that for conical bodies the formula is useful provided $\theta_n-\theta_m>10°$. For hypersonic speeds this implies cone-nose angles θ_n greater than 65°. Fig. 6 of Sinnott's paper shows that the poorest correlation of results from tests on spherically blunted cones also occurred when $\theta_m=\theta_n$.

Similar difficulties arise in the case of the ogive. Substituting $\Delta/R=K\cot\theta_m$ and $r/r_s=1-\cos\theta_n$ in equation (4) and re-arranging as an equation for K one finds that as $\theta_m\to\theta_n$ and $\delta\to0$ so K

POINTED BODIES

For a cone Sinnott's formula must eventually fail since at the conditions for shock detachment $\theta_m=\theta_n$ and $\delta=0$. Substitution of these values in equation (3) $\delta/r=K\cot\theta_m-\cot\theta_n$ gives $K=1$ not 0·77. In other words the stand-off distance measured from the shoulder of the cone is not independent of the forebody shape when θ_n is close to θ_m. This has often been noted before. Warren (1956)

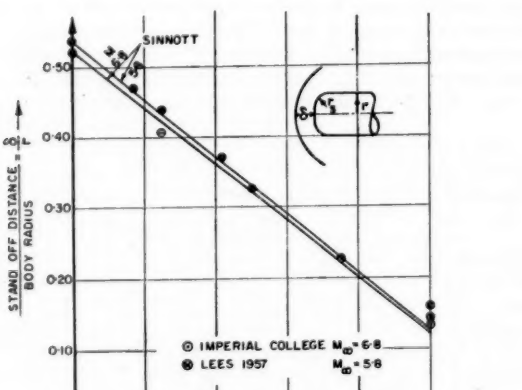


FIGURE 4. Variation of stand-off distance with shoulder radius.

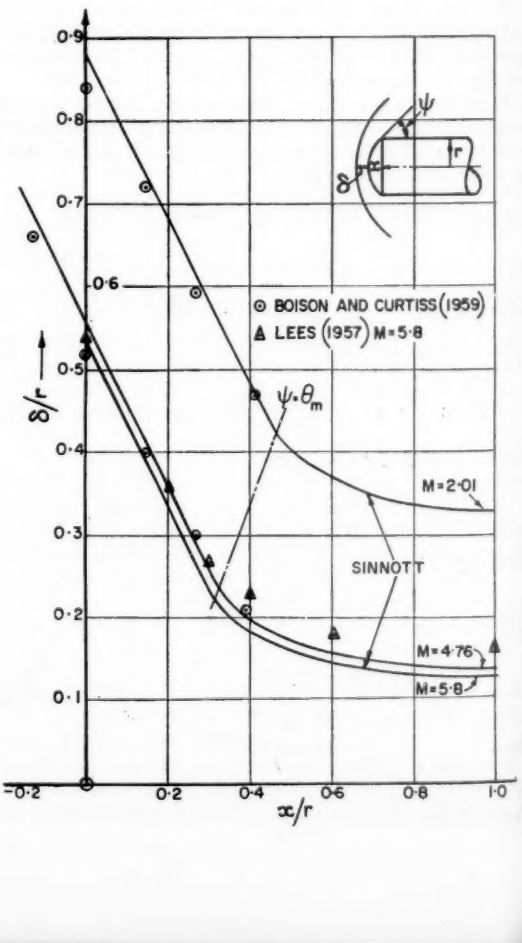


FIGURE 5 (*right*). Variation of stand-off distance with depth of spherical cap.

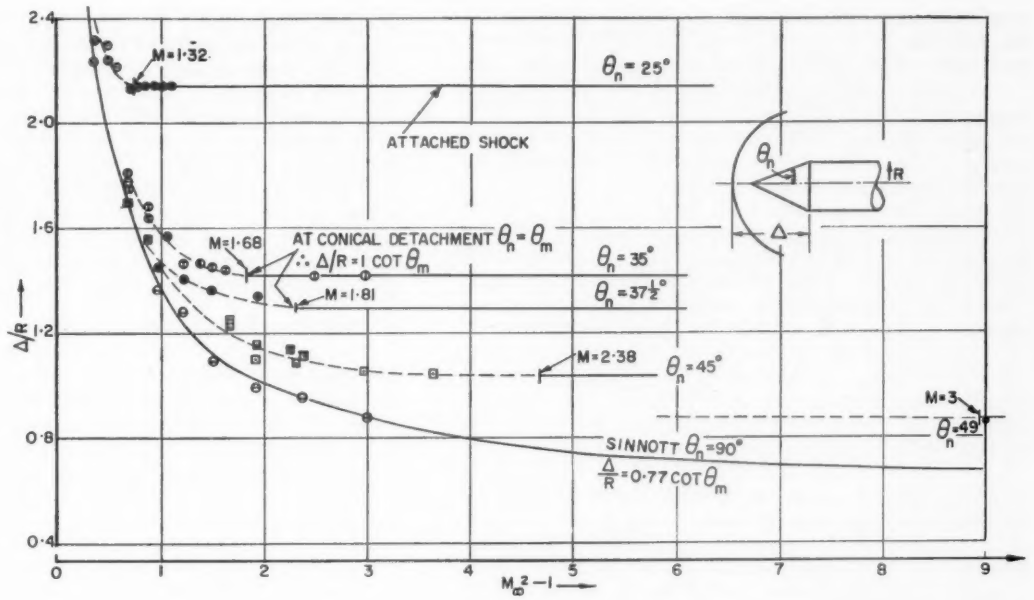


FIGURE 6. The variation of Δ/R with $(\theta_n-\theta_m)$.

approaches 1. The other limiting case is when $r_s/r\longrightarrow 1$, the body becomes a hemisphere cylinder and $K=0{\cdot}77$. As for the cone then, it appears that K is a function of nose geometry when θ_n is close to θ_m.

CONCLUSIONS

The formula proposed by Sinnott provides an extremely simple and reasonably accurate estimate of stand-off distance for a variety of blunt axisymmetric bodies. For pointed bodies the formula is useful only when the nose angle exceeds the conical shock detachment angle by more than ten degrees.

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The Stability of Flow Through Porous Screens

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1. INTRODUCTION

In many cases of the flow through porous screens, one may consider it to be made up of a number of jets passing through the openings of the screen. These jets are separated by a series of wakes behind the solid parts of the screen. The majority of investigations on the flow through such screens [1, 2, 3] have been concerned with the measurement of pressure drop and its variation with different flow conditions; it has been assumed that the pressure is discontinuous at the screen itself and that the pressure drop coefficient $\Delta p/\frac{1}{2}\rho v^2$ provides sufficient information, where Δp is the pressure drop across the screen, ρ the density of the fluid, and v the velocity of approach to the screen.

Originally received 25th January 1960, revised 25th April.

Such screens are often used to produce uniformity of flow in a stream of fluid, and some theoretical and experimental work has been reported [4, 5, 6]. Further tests have shown, however, that in certain cases there appears to be some instability of the flow, *i.e.* an irregular variation in the flow conditions behind the screen, the flow varying with time at a given point, together with a spatial variation with time behind a uniform screen. The word instability is used in the following work to describe these conditions, but it should be noted that in most cases this is a transient variation and the flow eventually settles down to a steady pattern behind the screen, provided that the approach flow is steady. This has not been widely studied, and an account is given below of previous investigations and the factors which influence the stability of the flow.

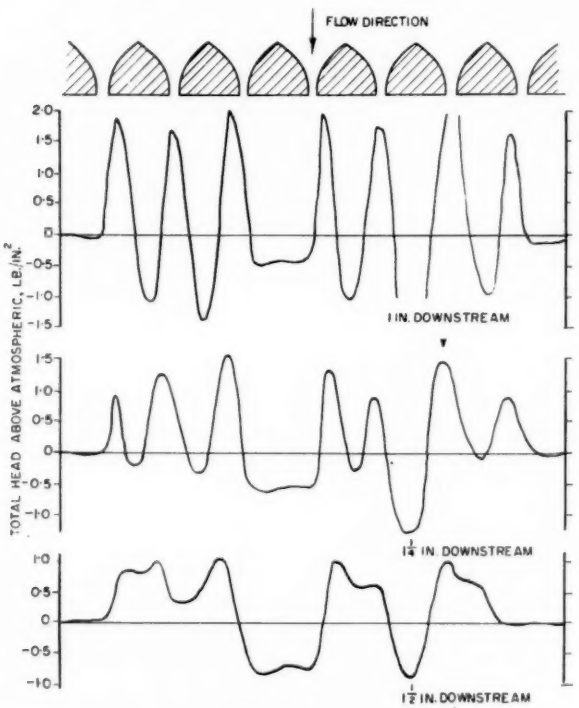

FIGURE 1.

2. PREVIOUS INVESTIGATIONS

The majority of experimental work has been concerned with two-dimensional flow, *i.e.* the plane flow through a screen, resulting in a number of parallel two-dimensional jets.

Ollsen[7] dealt with the flow through a grid of large open area ratio, but his work was mainly concerned with mixing in fully developed turbulent flow. It was complicated by the fact that the flow was not truly two-dimensional, since no precautions were taken to prevent inflow parallel to the rods. The first experimental report of instability of flow behind a screen was given by MacPhail[8], who was concerned with the method of obtaining uniform flow in a duct downstream of a simultaneous 90° bend and sudden expansion. Corner vanes alone at the bend were found to produce very irregular flow downstream when the vanes were close together. In view of his concern with the problem of obtaining a uniform velocity distribution, the instability aspect of the flow was not pursued.

The first complete theoretical and experimental investigation of the stability of flow behind a grid of rods in a closed duct was by von Bohl[9]. By varying the open area ratio of the grid, he was able to obtain both stable and unstable types of flow. His analysis was based on the small perturbation method, and gave the correct qualitative result, *i.e.* the degree of stability decreases with reduction in open area ratio of the grid.

A thorough investigation of the stability of two-dimensional flow through a grid of rods was described by Corrsin[10]. His screen was arranged so that a row of parallel two-dimensional jets was produced, and a series of total head traverses were made behind the screen. Only one open area ratio of the screen, 0·17, was tested, giving narrow jets with wide wakes, and instability was found in many cases. It consisted of the grouping together of adjacent jets immediately after their exit from the grid, thus causing wildly eddying flow. Adjacent groups then joined until at a short distance downstream from the grid there was little evidence to show that the flow had originated from a regular row of jets. The phenomena was found to be irregular, *i.e.* the same pairs of adjacent jets did not always unite first. Figure 1 shows typical results.

These two-dimensional investigations show the nature of the problem and the difficulties associated with measurement. They cover a limited field, and more attention was paid to the examination of possible methods of overcoming the instability than to the study of its mechanism.

3. THE PREVENTION OF INSTABILITY

The prevention of instability was examined by both MacPhail and Corrsin, who introduced wire mesh screens downstream of the grid under test. Measurements downstream of the combination showed that the jet appeared to be stable, but Corrsin pointed out that small variations or narrow irregularities which disappear with increasing distances downstream are apparently the fine mesh screen jets in the process of combining with one another; the stability of the main jets from the screen has been achieved but has been replaced by the instability of the jets through the openings in the fine screen, so that we are no nearer to an understanding of the original problem.

Corrsin also showed that the effectiveness of the second screen varies considerably with the spacing between the main plate and the small mesh screen. No stabilising effect occurs at all when the screen is placed immediately adjacent to the plate; the only effect is to increase the turbulence level of the jets before mixing. One aspect of Corrsin's work, however, which throws some light on the possible mechanism of the process is the partial stabilisation caused by replacing the true two-dimensional arrangement by one in which flow along the Z-axis is permitted, *i.e.* entrainment of air from the Z direction. One difficulty lies in the definition of the degree of stability of the system.

4. THE MECHANISM OF INSTABILITY

The physical mechanism of this coagulation of the jets appears to depend upon the entrainment of air by individual jets from the wakes between them. A possible mechanism for the instability is as follows. The entrainment reduces the static pressure between the jets tending to force them together. As the individual jet spreads out downstream it tends to act like a diffuser, so that the static pressure increases downstream. The pressure difference between the jets and the wakes is balanced by the differences in curvature of the stream-lines of the jets. Thus, for a series of jets, the wider the spacing between them the greater the diffusion angle between the individual jets before adjacent jets combine with one another. When the spacing between the jets is large enough, *i.e.* when the open area ratio of the screen is small, the necessary angle is prohibitively large and a breakdown or instability of the flow results. Bohl's measurements give an approximate confirmation of this hypothesis.

It would appear that, for given flow conditions, there might be a critical open area ratio for the screen below which instability of the flow might be expected and above which the flow might be regarded as completely stable, but this idea is difficult to convert into numerical form due to the difficulties associated with the definition of the stability of the flow. Bohl found that the open area ratios of 0·63 and 0·54 corresponded to a stable and an unstable condition respectively, while Corrsin dealt with only one

case, an open area ratio of 0·17, and observed definite instability. Corrsin used a shaped screen (Fig. 1), while Bohl used sharp-edged wooden slats. It is almost certain that the critical range of open area ratio (since it is felt that there is a gradual transition rather than a particular value) is influenced by the screen geometry and also by the flow conditions, typified by the Reynolds number. The limiting cases are an open area ratio of unity, *i.e.* uniform flow with no obstruction, which should be basically stable, and zero open area ratio, which should be basically unstable. It is difficult to see this intuitively, but it might be considered that in this latter case it will take much longer to entrain sufficient air with very small widely spaced jets in order to cause the necessary pressure reduction in the wakes to cause the jets to spread.

The instability mechanism is also influenced by the previously mentioned stabilising effect of a fine mesh downstream. It is suggested that this second small mesh screen might cause an effective increase in open area ratio by enforced spreading of the individual jets, but this point has not been thoroughly examined.

5. THREE-DIMENSIONAL FLOW

In the above sections, two-dimensional flow has been considered. In most practical applications, however, three-dimensional flow occurs through screens made of wire gauze and perforated plate. In these cases, we have a series of jets with wakes in between them, but there is no question of an inflow into these wakes from some other source. A similar description of the flow might be postulated, but in this case we have three-dimensional axially symmetric diffusers instead of two-dimensional.

The flow through screens of different open area ratios and the effect of open area ratio on the pressure drop have been widely studied, but no indication has been given of any observed instability. In the measurement of the pressure drop across screens, many investigators have merely measured the pressure drop between two tappings at certain fixed distances upstream and downstream of the screen; the inaccuracies of this method have already been discussed[11]. In the course of measurements of static and total pressures behind various screens instability of the flow has been observed in the form of sudden changes in pressure after a period of apparent steadiness. It was at first thought to be due to irregularities coming from upstream, but, with great care being taken to prevent upstream variations, changes in the total pressure with time at any given position downstream of the screen persisted. There has been some difficulty in measuring this instability at all accurately in the experimental work carried out so far, since the dimensions of the screens have been small and the total head probes used for measurement comparatively large. In connection with the variation of static pressure with time it has been found that, in general, the larger the open area ratio of the screen the less time it takes for the static pressure tapping readings to settle down to a steady value. It would appear that the use of the word instability is unfortunate, since in all cases the flow pattern eventually settles down to a stable form provided that the upstream flow conditions remain uniform.

Certain differences have been observed, however, between the flow characteristics of wire mesh screens and those of perforated plate screens. The perforated plates showed few signs of instability of flow over a wide range of flow conditions and different open area ratios, either for square or triangular pitch of the holes. On the other hand, for wire mesh screens of open area ratio below about 0·5 instability is observed, but the sudden changes in pressure consequent upon the combination of adjacent jets take place after a comparatively short time and, after these have occurred, no further changes appear.

It is suggested that this instability may be caused not only by the gradual entrainment of air from the wakes, but by irregularity in the spacing of the wires of the screen. This is borne out by careful measurements on the screens which have been used. For the perforated plates the spacing of the holes is very regular, particularly in the plates where the holes have been drilled individually as opposed to commercial punched plates. For the wire mesh screens, on the other hand, examination by means of a microscope shows that the variation in spacing of the wires is in the range of ± 5 per cent of the mean value. Instability in one "cell" could thus be caused by different pressures on each side of it, thus causing a deviation in the path of the jet and easier combination with adjacent jets, building up the instability across the whole area of the flow.

Another factor which is of interest in this connection concerns the change in stability when dust is deposited on the screen. Dust deposit has been a major problem in the development of the hot wire anemometer, and it has also been found in our work that contamination of wire gauze screens presents difficulties under continuous running conditions. The deposits are generally too small to affect the open area ratio of the screen, but it is considered that they affect the stability of the flow in a manner similar to that of irregularities in the wire mesh spacing. The problem of deposition on a wire gauze screen has not been widely studied although the principle has been used in certain applications[12]. Our preliminary studies have shown that most of the oil and dust deposit occurs in the regions where the wires cross one another and very little on the free regions of the wire, but this question requires further investigation.

No mention has yet been made of the effect of the turbulence level on the flow irregularity. Schubauer[13] has mentioned this coalescence of jets in certain circumstances and states that open area ratios of less than 0·5 may produce large spatial variations in velocity, sometimes accompanied by time variations having the character of a high turbulence. No facilities have been available for turbulence measurement, but there may be a relationship between the level and type of turbulence and the phenomena previously described.

6. CONCLUSION

The unsteady flow through porous screens of different geometries has been discussed, and some suggestions have been made concerning possible mechanisms for it. The experimental work on this topic has so far been rather meagre and has only dealt with particular screens, most attention being paid to the prevention of instability. To remedy this, a programme of work has been started to provide a better understanding of the problem. It is hoped to deal with the following topics:

(*a*) A detailed examination of the flow through a large scale model of a wire gauze, with carefully controlled upstream conditions. The form of the jets and wakes will be measured and the effect of irregularity in the mesh can also be studied.

(*b*) The relation between the instability of the flow and the pressure drop through the screen.

(*c*) The effect of the use of screens for velocity distribution modification upon the stability of the flow.

(*d*) The relation between the turbulence of the flow and the irregular time variations of pressure and velocity described earlier.

(*e*) A study of deposition on screens of different geometries.

(*f*) The effect on stability of screens at an angle to the main flow.

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Supersonic Flutter of a Cylindrical Panel in an Axi-Symmetric Mode

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IN REF. 1 an extensive review was made of the panel flutter problem and analyses dealing with flutter of cylindrical shells of finite length were discussed in considerable detail. It was stated that one of the central points of controversy is in the choice of the appropriately simplified governing equations for the thin-walled elastic shell. Related to this is the choice of flutter mode and the question as to how the critical flutter speed depends upon the number of circumferential and axial waves in that mode.

Stepanov[2] and Strack and Holt[3] found that the critical Mach number decreases with increasing number of circumferential waves, and Fung[1] has concluded that the axially symmetric mode is of the greatest interest.

The purpose of this note is to present a relatively simple analysis in which only axi-symmetric deformations of the shell are considered. The shell is assumed to be unreinforced longitudinally.

NOTATION

A_r, A_s modal coefficients
a radius of cylinder
B, C functions of r and s in equation (7*a*)
$D = Eh^3/12(1-\nu^2)$. Flexural rigidity/unit width of shell
E Young's modulus
h shell thickness
K constant in equations (10) and (11)
L shell length between supports
m shell mass per unit surface area
M Mach number
n number of circumferential waves
N_x tensile force/unit width acting in midplane of the shell in axial direction
$-N_{xr}$ critical value of N_x to cause symmetrical buckling
q dynamic pressure
r, s number of axial half-waves in assumed modes
U velocity of supersonic stream
W radial deflection of shell
X axial co-ordinate measured from end of shell
Z lateral pressure on the shell
$\beta = \sqrt{(M^2-1)}$
ρ density of supersonic stream
ν Poisson's ratio
λ frequency of oscillation.

Received 13*th April* 1960.

ANALYSIS

A theory of axi-symmetric deformations of a cylindrical shell has been presented in Ref. 4 which results in the following equation for the shell radial deflection, W,

$$D\frac{d^4W}{dx^4} + \frac{Eh}{a^2}W - N_x\frac{d^2W}{dx^2} = Z \quad . \quad . \quad (1)$$

For the flutter problem, the effective lateral pressure Z contains aerodynamic terms and oscillatory inertia terms proportional to the shell mass. If linear piston theory is used to derive the aerodynamic forces and simply supported deflection modes of the form $W = \Sigma A_r \sin(r\pi x/L)$ are considered, then equation (1) becomes, for the r^{th} mode,

$$\left[D\left(\frac{r\pi}{L}\right)^4 + \frac{Eh}{a^2} + N_x\left(\frac{r\pi}{L}\right)^2\right]\sin\frac{r\pi x}{L} = -\left[\frac{\rho U^2}{M}\left(\frac{r\pi}{L}\right)\cos\frac{r\pi x}{L} + \left(\frac{\rho U i\lambda}{M} - m\lambda^2\right)\sin\frac{r\pi x}{L}\right] \quad (2)$$

where U and M are velocity and Mach number of the supersonic flow passing in an axial direction along the surface of the cylindrical shell.

If only two degrees of freedom are considered in this analysis involving the modes $A_r \sin(r\pi x/L)$ and $A_s \sin(s\pi x/L)$ then by applying the Galerkin process, the following flutter determinant is obtained.

$$\begin{vmatrix} D\left(\frac{r\pi}{L}\right)^4 + \frac{Eh}{a^2} + N_x\left(\frac{r\pi}{L}\right)^2 - m\lambda^2 + \frac{\rho U i\lambda}{M}, & \frac{\rho U^2}{LM}\,\frac{4rs}{s^2-r^2} \\ -\frac{\rho U^2}{LM}\cdot\frac{4rs}{s^2-r^2}, & D\left(\frac{s\pi}{L}\right)^4 + \frac{Eh}{a^2} + N_x\left(\frac{s\pi}{L}\right)^2 - m\lambda^2 + \frac{\rho U i\lambda}{M} \end{vmatrix} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where the condition that $(r+s)$ must be odd applies. The substitution is now made into equation (3) that

$$\left.\begin{aligned} D\left(\frac{r\pi}{L}\right)^4 + \frac{Eh}{a^2} &= -N_{xr}\left(\frac{r\pi}{L}\right)^2 \\ \text{and } D\left(\frac{s\pi}{L}\right)^4 + \frac{Eh}{a^2} &= -N_{xs}\left(\frac{s\pi}{L}\right)^2 , \end{aligned}\right\} \quad . \quad . \quad (4)$$

where $-N_{xr}$ and $-N_{xs}$ are the critical values of N_x for symmetrical buckling of the shell in compression[4]. Hence, on expanding the determinant, and separating the resultant equation into imaginary and real parts, one obtains respectively

$$2m\lambda^2 = \left(\frac{r\pi}{L}\right)^2\left[N_x - N_{xr}\right] + \left(\frac{s\pi}{L}\right)^2\left[N_x - N_{xs}\right], \quad (5)$$

$$\text{and } \left\{\left(\frac{r\pi}{L}\right)^2\left[N_x - N_{xr}\right] - \left(\frac{s\pi}{L}\right)^2\left[N_x - N_{xs}\right]\right\}^2 = 4\left[\frac{\rho U^2}{LM}\cdot\frac{4rs}{s^2-r^2}\right]^2 - 4\left[\frac{\rho U\lambda}{M}\right]^2 \quad . \quad . \quad (6)$$

The last term in equation (6) represents the effects of aerodynamic damping, which probably can be neglected (this can be justified as in Ref. 5). If this is done, equation (6) becomes, after some manipulation,

$$\frac{2qL^3}{MD} = \frac{\pi^4}{8}\frac{(r^2-s^2)^2\,(r^2+s^2)}{rs} + \frac{N_x\pi^2L^2}{8D}\frac{(r^2-s^2)^2}{rs} \quad . \quad (7)$$

$$= \frac{\pi^4 C}{8} + \frac{N_x\pi^2L^2B}{8D} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7a)$$

It is of interest to determine the most critical combination of modes, in this binary flutter problem, which give the lowest flutter speed and Table I shows values of C and B for various combinations of r and s. It is seen that C is least when $r=s\pm1$ and when both quantities are also least, *e.g.* when $r=2$ and $s=1$. For widely separated modes ($r\gg s$) the coupling between the modes is small and both C and B become large, indicating a high flutter speed.

Thus it would seem that the lowest flutter speed occurs for the modes $r=2$ and $s=1$ when,

$$\frac{2qL^3}{MD} = \frac{9\pi^4}{16}\left(5+\frac{N_xL^2}{\pi^2D}\right). \quad . \quad . \quad . \quad . \quad (8)$$

This result is identical to that obtained for the two-dimensional flat panel in Ref. 5 and thus it can be seen that the flutter speed for a circular panel oscillating in an axi-symmetric mode is independent of the shell radius. It was pointed out in Ref. 5 that if aerodynamic damping can be neglected then "static" aerodynamic forces given by Ackeret are more accurate than those given by piston theory. This modification involves replacing M by $(M^2-1)^{1/2}$, or β, in equation (8), which then becomes, with $N_x=0$,

$$\frac{2qL^3}{\beta D} = 274. \quad . \quad . \quad . \quad . \quad (9)$$

TABLE I

r	s	C	B
2	1	22·50	4·50
3	2	54·16	4·16
4	3	102·08	4·08
5	4	166·05	4·05
4	1	956·25	56·25

This result, which is for a simply supported shell, is shown graphically in Fig. 4 of Ref. 5, and can be compared with results presented in Ref. 3, which become, after some manipulation,

$$\frac{2qL^3}{\beta D} = K, \text{ for no circumferential waves } (n=0) \quad . \quad (10)$$

and

$$\frac{2qL^3}{\beta D} = K\frac{12\,(1-\nu^2)}{n^4}\left(\frac{a}{h}\right)^2 \quad \text{for } n\neq0, \quad . \quad . \quad (11)$$

where $K=360$ for both ends simply supported

$=480$ for clamped-simply supported edges

$=720$ for clamped-clamped edges.

It is seen that equation (9) is more conservative than the corresponding equation (10), *i.e.* $K=274$ compared with $K=360$. This is probably mainly due to the different aerodynamic assumptions made.

By comparing equations (10) and (11) it can be shown that $n=0$ is more critical than $n\neq0$ unless

$$n^4 \geqslant 12\,(1-\nu^2)\left(\frac{a}{h}\right)^2 \quad . \quad . \quad . \quad (12)$$

For a shell with $a/h=400$ this implies $n\geqslant36$ and for this number of circumferential waves the circumferential mode is essentially circular anyway.

CONCLUSIONS

It has been shown that the flutter speed of a cylindrical panel in an axi-symmetric mode is independent of the shell radius and is least when the number of axial waves is also least.

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THE BRANCHES

The Spring, 1960, BRANCHES CONFERENCE of the Society was held at BROUGH, Yorkshire, on Saturday, 30th April.

"PROSPECTUS *of a Society for extending the application and improving the practice of the Art of Arial Navigation to be entitled the* ROYAL AEROSTATIC INSTITUTION.

The vast extent of the atmosphere, the paramount influence it exerts over all our movements whether of pleasure or of profit, the share which it contributes to the maintenance and formation of so many brilliant and important phenomena, and the ready means of transport it affords to bodies which are or might be fitted to avail themselves of its advantages, all combine to render it a subject of peculiar concern to the philosophical enquirer, and point with special interest to that Art, by means of which alone our acquaintance with it can be enlarged, or our dominion over it extended and confirmed".

It could be thought that this was the Prospectus that led to the formation of our Society in 1866, but in fact it was written by Sir George Cayley in 1840. And as a Yorkshireman and the "Father" of dynamic flight, Cayley's memory was very much alive at this Conference held in the Flying School at Blackburn Aircraft Ltd. and organised by the Brough Branch.

It was perhaps coincidental, but still significant, that a question was put to the Conference Chairman, Dr. Ballantyne, as to whether the new Lecture Hall at 4 Hamilton Place, was to bear a name. He answered that the CAYLEY HALL was in the minds of some: the Autumn Branches Conference will be held in the new Hall, and there can surely be no doubt now that it will be a memorial to Sir George Cayley. And of the Branches, Brough has perhaps made the biggest financial contributions and deserves this honour.

This Conference was indeed a triumph for Brough, not only by way of organisation and entertainment, but literally so in that the awards of the N. E. Rowe Medal Competition were announced—and both (the under and over 21 years) were won by Brough! Understandably Mr. N. E. Rowe, if only as President of the Brough Branch, was wreathed in smiles.

Even the weather was perfect for this second Conference away from London, which began on the Friday evening with a reception in the Flying School. (This was, rather than is, the literal fact, and an enquiry to hire an Auster led to considerable mathematics for the alternative of a Beverley. The NA.39 is not yet available to P.P.L. pilots.)

Both these aircraft—the latter from a discreet distance—were seen on a tour of the Blackburn Works, together with the Turbomeca range of gas-turbine engines. The modern was followed by the historical in a fascinating film which surely lends itself to a T.V. programme as "Wings in the East". The film, starting from stills of the original Blackburn with the garden seat, progressed through the Kangaroo and Cubaroo to the flying boats such as Iris and Sydney, through the war years of Skua and Roc, thence to Firebrand, Beverley and to the deck landing trials of the NA.39, since released as the "Nimbus". How appropriate a name, in that Cayley wrote of the "vast extent of the atmosphere", and if the film is formalised with a sound track, may this page suggest that Cayley's work have some part in the Introduction.

The Conference was attended by 48 members of 28 Branches, and was honoured by the presence of the President-Elect, Dr. E. S. Moult, who flew north in his own D.H. Dove: several flew back with him on the Saturday, including Miss Barbara Croad, Secretary of the Conference, for whom this was her first flight.

Visitors to the Conference were the guests of Brough members, and 16 guests stayed on for two nights to go sightseeing or seek local entertainment. Two guests were accompanied by their wives, and one, when introduced to her host's wife, found the astonishing coincidence that they had been great friends at school.

If this account veers on the social, it is because this was one of the aims of provincial Conferences, to be alternated with the Metropolitan meeting.

Much of the business of the Conference was given to the Lecture Hall, and Dr. Ballantyne announced that some £1,100 had been donated by Branches: this had been received with gratitude by the Council, but more was still welcome, and the Society would have to forfeit some income from the sale of securities to meet current bills: while this page does not wish to steal the thunder of later announcements, delegates were most interested in the technical installations, including closed-circuit television and full language interpretation services which will make the Hall unique in Britain. There was even the possibility of a T.V. transmission to Birmingham of the Opening Ceremony, to which Branches would get official invitations.

Some 60-65 R.Ae.S. Meetings were already scheduled, but outside these dates the Lecture Hall would be available for Branch occasions that lent themselves to a London venue.

Dr. Moult spoke of the growing strength of the Society in spite of a retraction in the Aircraft Industry, which he considered a realignment to strengthen ourselves for the days to come. The Society had much to do, and this included the Branches, now so great a part of its corporate strength.

Much other business was also discussed and decided upon, some of a parochial nature as to Society haberdashery and of contributions to this page: this was wholly domestic, but is mentioned here for those who were present and who will appreciate the full portent of this reminder. . . . The Conference was an important and enjoyable occasion, and our thanks and congratulations are due to the Officers and Members of the Brough Branch of the Royal Aerostatic Institution.—G. W.-W.

The Branch representatives who attended the Branches Conference, with (in the centre), Dr. E. S. Moult, the President, Dr. A. M. Ballantyne and Miss Croad, at Brough on 30th April.

Graduates' and Students' Section

Cricket match and dance

This is a final reminder about the Committee *v.* The Rest cricket match to be held at the Handley Page Sports Ground at Cool Oak Lane, Hendon, on Friday evening 24th June at 7 p.m. There is no charge so do come along and support us and stay for the informal dance afterwards.

If you are interested in getting some exercise, even though you cannot play cricket, please get in touch with either The Rest's organiser: Mr. M. Moulton, c/o Queen Mary College, Mile End Road, E.1, *or* Mr. A. H. Fraser Mitchell, 59 Cambridge Road, Kingston-on-Thames, whose telephone number is GLAdstone 8000 (Extn. 29) during office hours.

Future visit

We have been invited to visit Blackburn and General Aircraft at Brough on Saturday afternoon 24th September 1960. We will accept this if there is sufficient interest from members. It has been arranged for a Saturday afternoon so that London members will be able to go by train if they wish.

Will all members interested in this visit please contact the Hon. Visits Secretary, N. R. Craddock, 5 Oxleay Road, Harrow, Middlesex, by 31st August at the latest.

Company Views on Recruitment

If one wants to rise to a high technical position in the Aircraft Industry, it is better by far to have a university degree than a Higher National Certificate. This is only one of the conclusions that can be drawn from answers sent in by twelve leading companies who were questioned about the recruitment of technical staff. Although answers were received before the recent major reorganisation of the Industry, they can still be considered representative. Replies were received from aircraft, aero-engine and missile companies.

Asked about the qualifications they require in recruits, companies replied that they wanted graduates in aeronautical, civil, mechanical and electrical engineering as well as maths. and physics graduates. Certain companies said that only honours graduates were needed; in one case first-class honours were required for many posts. In general there was felt to be only a small need for such specialists as maths. and physics graduates. There appeared to be little requirement for more specialised training than in the past, except for electrical and electronics work.

Asked about the proportion of graduates in their technical staff, companies gave widely varying figures. The trouble, of course, is definition of technical staff. For example, one company said its aerodynamics department was made up of 95 per cent graduates and 5 per cent of people with Higher National Certificates; in the drawing office, 10 per cent were graduates. Another said that approximately 45 per cent were graduates, but that technicians and draughtsmen with H.N.C. " are still very satisfactory for some of the second-line positions." Yet another gave varying proportions for different departments, ranging from 59 per cent graduates in aerodynamics to 20 per cent in flight testing and engineering research. In the technical staff of three other companies 32 per cent, 23 per cent and 14 per cent were graduates, 22·5 per cent, 23 per cent and 20 per cent respectively had H.N.C. The second and third of these companies had technical staffs totalling 314 and 769 people respectively.

In two cases no answers were given to this question, and two other companies rather evaded it, saying in one case that they had one graduate for every three staff members with a National Certificate, and in the other that the ideal proportion would be 50 per cent graduates and 50 per cent people with H.N.C.

Apprenticeship v. Direct Entry

Questioned about the best form of training for a technical career in the Industry, a decided preference for a 1-3-1 degree sandwich course was shown, with the trainee spending three years of study for a university degree sandwiched between two years of practical training.

Varying views were expressed on the merits of direct graduate entry versus apprenticeship training. One company felt that apprenticeship training is more acceptable on the design side because it is more practical. " On the other hand the direct entrant has often a deeper insight into the more scientific aspects of technical development, and in some respects he may be at an advantage in having no preconceived ideas about the firm he joins." This company felt that a roughly even division between apprenticeship engineers and direct entrants was most suitable for it.

Another view was that " for the first two years the ex-apprentice with H.N.D. or H.N.C. is more valuable than a graduate direct from university . . . After two years, however, it is noticeable that the good graduate begins to forge ahead. The ex-apprentice soon appears to reach his ceiling, whereas the good graduate goes on. There are, of course, exceptions." Most companies emphasise that both types of person are needed.

Similar views were expressed by other companies. " The ex-apprentice with H.N.C. is more useful initially in the systems department and other practical work, but the good graduate has greater potentiality in advanced theoretical work and the better graduates of universities have personality advantages." One company gave its view department by department, emphasising in nearly every case that both types were needed. For structures the view was " little to choose between the two, university man usually brighter "; the electrical and electronics department stated that " engineering apprentices form backbone of department, but lack higher analytical qualities of university graduate."—J.R.C.

(To be concluded)

THE LIBRARY

Reviews

THE THEORY OF MATRICES. 2 Volumes. *F. R. Gantmacher. Chelsea Publishing Company, New York, 1959. 373 pp. and 276 pp. 12 dollars.*

This book is translated from the Russian and is stated in the Preface to be based on lecture courses on the theory of matrices and its applications given by the author during the past seventeen years in the Universities of Moscow and Tiflis and at the Moscow Institute of Physical Technology. It is also stated "This book is meant not only for mathematicians (undergraduates and research students), but also for specialists in allied fields (physics, engineering) who are interested in mathematics and its applications. Therefore the author has endeavoured to make his account of the material as accessible as possible, assuming only that the reader is acquainted with the theory of determinants and with the usual course of higher mathematics within the programme of higher technical education." It may be said at once that the book is a systematic treatise on the theory of matrices and that, on the other hand, it is *not* a systematic treatise on the applications of matrices. The only chapters devoted to applications are the two final ones which are concerned with systems of linear ordinary differential equations and with Routh-Hurwitz stability criteria and allied matters.

The first volume is concerned with basic matrix theory which is covered very thoroughly. Some of the chapter headings are: Matrices and Operations on Matrices, Linear Operators in an n-Dimensional Vector Space, The Characteristic Polynomial and Minimal Polynomial of a Matrix, Functions of Matrices, Matrix Equations, Quadratic and Hermitian Forms and Equivalent Transformations of Polynomial Matrices—Analytic Theory of Elementary Divisors. The second chapter deals with the solution of sets of linear algebraic equations by the "algorithm of Gauss" and allied matters. A remarkable feature of the exposition here is the inclusion of a mechanical interpretation of the Gaussian algorithm based on the small deflections of a straight beam. This excursion into engineering is, however, quite exceptional, for the general treatment is abstract.

The first three chapters of the second volume continue the general theory and are headed: Complex Symmetric, Skew-Symmetric, and Orthogonal Matrices; Singular Pencils of Matrices; Matrices with Non-Negative Elements. Then follows the chapter on systems of linear differential equations, including the theory of the matrizant (which is called the matricant); this seems to the reviewer to be particularly valuable. So far as aeronautical engineers are concerned, the final chapter on "The Problem of Routh-Hurwitz and Related Questions" will probably be of greatest interest. The basic theory is developed *ab initio* and with great thoroughness, but, as elsewhere, the computational aspects of the matter are not considered. It was of great interest to the reviewer to find it recorded in this Russian book that Clark Maxwell's 1868 paper "On Governors" was responsible for starting the whole of the modern theory of stability; this led directly to Routh's comprehensive investigation, as published in his Adams Prize Essay (and it may be added that Maxwell was responsible for choosing this topic for the Adams Prize).

The reviewer was interested to find that the expression for the penultimate and critical test function (which is of paramount importance in the applications) in terms of the roots of the characteristic equation, as given in his book "The Principles of the Control and Stability of Aircraft," was discovered by L. Orlando in 1911 and is discussed under the heading of "Orlando's Formula" in the book under review.

To sum up, this is a very valuable and interesting book which will appeal to all who are interested in the theory of matrices. In spite of the disclaimer in the Preface, the mathematical level is pretty high and the approach rather abstract. Applications, except the two already mentioned, are not treated directly and computational matters are not treated at all. The author's outlook seems to be completely international and the translation is well done. One minor error noted by the reviewer is that the well-known engineer Stodola appears as "Stodol."—W. J. DUNCAN.

Note: The publishers have drawn our attention to the fact that a translation of this book has also been published by Interscience Publishers Ltd., with the title *Applications of Theory of Matrices* by F. R. Gantmacher.—*Ed.*

SPACE FLIGHT. *Krafft A. Ehricke. Vol. I, Environment and Celestial Mechanics. D. Van Nostrand, London, 1960. 513 pp. Illustrated. 109s.*

This is the first of three volumes on Space Flight which Krafft A. Ehricke is contributing to the series *Principles of Guided Missile Design*. As its subtitle implies, it deals mainly with the space vehicle's environment, which is interpreted as the solar system, and "celestial mechanics," that is, the orbits of unpowered space vehicles. Volume II will discuss the dynamics of powered vehicles, and Volume III will be entitled *Space Operations*.

It should be said at once that Volume I, which is complete in itself, is by far the most thorough exposition of the subject which has yet appeared, and can scarcely fail to become a standard textbook. In the first 70 pages Mr. Ehricke describes the historical background of space flight, from the speculations of the ancient Greeks to the first actual launchings; he then goes on to discuss the usefulness of space flight, a critical question, now that the technical problems seem soluble—at a price. It is greatly to Mr. Ehricke's credit that, in answering this question, he does not invent military justifications for astronautics. Instead he propounds a rationale of space travel, based on the thesis that life has a primal urge to expand to the limits of its environment: aquatic creatures made the enormous effort of adapting themselves to land, and a continuation of this process will ensure the development of space travel. Though this analogy has its flaws, some such explanation must be attempted, since space flight has passed beyond the age of mere faith, and needs a plausible philosophy to sustain it.

Pages 113-259 of the book are devoted to an excellent detailed survey of the solar system with a wealth of helpful tables, and many graphs of close grid. The physical properties of the earth, its gravitational field and atmosphere, occupy a large proportion of this section, but the information on the planets and, particularly, the asteroids is much fuller than is usual in astronomical textbooks.

Pages 261-506, which are largely mathematical, describe the orbits of bodies in a central force field, and the effect

of perturbations. The material is more intelligibly presented than in most textbooks on celestial mechanics, and is carefully chosen for its relevance to space flight. For example, Mr. Ehricke discusses the "sphere of influence" of a planet in the presence of the sun, a subject which, although ignored in twentieth-century textbooks of celestial mechanics, is important for astronomical orbits, because they will often be aimed to pass near planets.

Despite its general excellence, the book has many minor faults, which, since it is otherwise so authoritative, must be emphasised. The worst defect is that much of the information on the earth's atmosphere is out of date: it is rather ironic that the first proper textbook on space flight should so pointedly ignore the results of space research since 1957. Apart from a short section on the radiation zones, inserted in proof, the book can be regarded as of 1957 vintage. Though it is true that printing delays are now a major brake on scientific progress, it should have been possible, in a book published in 1960, to insert a sentence saying that the values given for air density have proved to be in error by a factor of more than 5 at heights above 220 km., a fact which was known by November 1957. The second fault is that, for a standard work, there are far too many errors and misprints, though the majority of these are harmless or picturesque—like "asprophysics" on p. 98. The other faults are mainly defects in layout: for example, the method of giving references is confusing, some appearing as footnotes and some in lists at the end of chapters.—D. G. KING-HELE.

BERYLLIUM, METALLURGY OF THE RARER METALS. No. 7. *G. E. Darwin and J. H. Buddery. Butterworths Scientific Publications, London, 1960. 392 pp. Illustrated. 70s.*

Somewhat less than a million years ago, Man inherited the Earth, but he long remained and, to a large extent, still remains ignorant of his heritage. Over seventy metals were and are available to him, but his first discovery in this field, copper, was not made until about 5,000 years ago. Some 2,000 years later he became possessed of another, iron, Kipling's "master of them all." As time went on more came to light; slowly at first, but, as alchemy turned from its association with the Black Arts to become chemistry, at an ever increasing pace.

At the end of the 18th century, one of the scientific pioneers, Vanquelin, suspected the presence of a then unknown alkaline earth element in the mineral beryl. He was unable to isolate it: this was, however, done a generation later by Wöhler. Vanquelin, with commendable restraint, did not name his evasive element, but since he had noted that its water soluble salts were sweet to the taste (we now know they were also toxic), his editors subsequently gave it the name Glucinum. This remained in use up to the beginning of this century, when, abandoning the gastronomic association, the present name, Beryllium, to some extent indicative of its origin, was adopted.

In 1885, Humpidge prepared the pure metal: Beryllium was thus born, but like many another child was at first unappreciated. Initially, it merely filled in what had been a blank in Group II, A, of Mendeljeff's Periodic Classification, a position of significance only to the few. However, as the properties of this new metallic element became known, in a diversity of ways, uses generally rather outside the normal engineering field, were and continue to be found for it. Contemporaneously, it is employed for windows in X-ray tubes, electrodes in neon lights, targets in cyclotrons, as sheaths in nuclear reactors, and so on. It is also used as a deoxidiser of copper, as a constituent of a very strong precipitation-hardening copper alloy, in other alloys, many having thermo-nuclear applications and finally, and quite importantly, it is used in the manufacture of spark free tools.

When the engineer and particularly the aeronautical engineer realised that this metal has a specific gravity of 1·8, a Young's modulus of about 43×10^6 lb./in.^{2} and a melting point of over 1,200°C, his interest was not unnaturally stimulated. Darwin and Buddery, the authors of the book under review, have produced a work of nearly 400 pages which can do much to assuage this. It is not, of course, the first work dealing with this metal. In 1909, Parsons published his *Chemistry and Literature of Beryllium*: in 1929, the Siemens-Konzern issued *Beryllium-Arbeiten*, a tome subsequently translated into English by Rimbach and Michel and, in 1932, published in America, while in 1955, there appeared a most informative work with a strong engineering bias, *The Metal Beryllium* by White and Burke.

The present production has much to commend it. It is up to date, well written and, as would be expected, well reproduced. The illustrations, chiefly line drawings and graphs (though there are a few photographs) are in generous supply. In all, the book contains twelve chapters, a seven page chemical analytical appendix and an adequate index. The scope of the work is wide. It covers the historical ground and the whole of the physical and chemical techniques used in producing the metal from the few minerals in which it occurs. The many and various complexities involved in its fabrication are lucidly described. Its physical, chemical and mechanical properties are well discussed. Existing and possible Beryllium alloys are considered and, what is most important at the present time, the outstanding nuclear properties of the metal receive careful survey. Finally, health hazards which could be devastating, were they neglected, receive attention.

As a means of making extremely strong copper alloys, Beryllium has long arrived. In nuclear engineering it can and does render services unobtainable from current alternatives. Because of its unique *specific* Young's modulus and other mechanical properties, some wonder if it can enter the aeronautical structural field. At a present cost of about £25/lb. for hot pressed, rough machined blocks, one feels, at least in this Blue Streak year, some measure of restraint will be exercised. Aircraft with Beryllium structures are not in sight nor are they likely to be seen soon by those of sober vision.—P. L. TEED.

TURBULENCE. *J. O. Hinze. McGraw-Hill, London, 1959. 586 pp. Illustrated. £5 16s. 6d.*

The past twenty years have seen the publication of a very large number of papers describing experimental and theoretical work on the properties and nature of turbulent flow, and it is certain that we know more about turbulence than we did when *Modern Developments in Fluid Dynamics* was published in 1938. On the other hand, no balanced and comprehensive account of the subject has appeared since then, which suggests strongly that most of this work has been more destructive of existing theories rather than productive of new ones. The destructive aspect of recent work arises from the detailed knowledge that we now have of the fluctuating velocity field and the consequent difficulty of devising an acceptable theoretical model. This is well illustrated by the two diagrams chosen to decorate the dust-cover of this book, an energy-balance diagram and a sketch illustrating the phenomenon of intermittency. The energy relations shown in the first diagram are decisive in assessing the validity of approximations used in any theory and the situation depicted in the second is one characteristic of a whole class of flows and

completely resistant to theoretical analysis. The constructive side of this work is that the physical meanings of phenomenological theories are much better understood and so it is possible to set limits to their range of validity. Professor Hinze describes the present state of the theory of turbulence by presenting in some detail the theory of homogeneous, and in particular, isotropic turbulence which has provided the concepts and inspiration for the detailed study of shear flows although hopes that it would lead directly to an analytical theory of turbulence have faded. The essential difference between homogeneous turbulence and turbulent shear flows is the occurrence of transport of momentum, energy and heat, and the nature of this transport is discussed in some detail and from several points of view. This is followed by accounts of the structures of free and wall turbulent flows with comparisons of the observations with the various theories. An unexpected but very welcome chapter describes the experimental techniques used in the study of turbulent flows, and in particular the techniques of hot-wire anemometry. This book is intended to provide an introduction to the subject for engineers with problems whose solution may be helped by a knowledge of the specialised literature, and so the treatment is very comprehensive and unbiased. It is undoubtedly a very useful reference book with very few important omissions and a detailed reading should provide the intended introduction. My only objection to this comprehensive and impartial account is that it tends to obscure the constructive aspects of the work, but this could be remedied by reading other publications in this field.
—A. A. TOWNSEND.

Additions to the Library

A.B.C. of "Electronic Brains," The. A series of six talks broadcast in the External Services of the B.B.C. Leon Bagrit. B.B.C., London. 1960. 47 pp. Illustrated. 1s. 6d. The author of these talks is Managing Director of Elliott-Automation Ltd. He has made a successful attempt to interpret the technical language usually associated with computers into language that could be understood by the "average listener." The booklet is plentifully illustrated with pictures and diagrams.

Advanced Propulsion Systems. Edited by Morton Alperin and G. P. Sutton. Pergamon Press, London. 1959. 237 pp. Illustrated. 45s. Contains the unclassified and recently declassified papers presented at the First Advanced Propulsion Systems Symposium, sponsored by the United States Air Force Office of Scientific Research and by the Rocketdyne Division of North American Aviation, and held in Los Angeles in 1957. Subjects covered include ion propulsion systems, thrust from plasma, solar heating, aircraft applications of nuclear power plants, direct power conversion, liquid propellants, ozone-fluorine, the use of metals and metal hydrides in rocket and jet propulsion, human hazards of space flight, research on free radicals as rocket propellants, and system considerations affecting new propulsion applications.

Aeronautic: Discussions held at the Aeronautic Production Forum in Los Angeles, Calif., 5-10 October 1959. Society of Automotive Engineers, New York. 1959. 115 pp. Illustrated. No price quoted. This is in the SP series and is numbered 329. It should not be confused with SP-327 which bears the same title but was held seven months earlier in New York. "Aeronautic" here should be read in its missile sense and the accent is on high-temperature production methods and requirements.

Algunos Ejemplos de Accion Internacional Para Resolver Los Problemas de la Era de la Reaccion. W. Binaghi. C.S.T.A., Rome. 1960. 13 pp. No price. An English summary gives this as "Some examples of international action aimed at solving jet age problems." The author is President of the Council of I.C.A.O.

Beauty of Gliding, The. Introduction by Philip Wills. Max Parrish, London. 1960. 95 pp. Illustrated. 35s. *To be reviewed.*

Beryllium. Metallurgy of the Rarer Metals, No. 7. G. E. Darwin and J. H. Buddery. Butterworths Scientific Publications, London. 1960. 392 pp. Illustrated. 70s. *Reviewed* on p. 367.

Biophysical Factors in a Human Lunar Ecosystem. T. C. Helvey. Biophysics and Astrobiology Branch Radiation, Inc., Florida. 1960. 75 pp. Illustrated. No price. Further evidence of the American determination to leave nothing to chance. Anticipates, among other subjects, the effect of space travel on the libido.

Design for Flight. The Kurt Tank Story. H. Conradis. Macdonald, London. 1960. 246 pp. Illustrated. 21s. *To be reviewed.*

Engineering Features of Rear Engine Installations in Transport Aircraft. E. S. Allwright. Lecture to Royal Aeronautical Society, London. 1959. 12 pp. Illustrated. An advance proof of the lecture delivered to the Society on 17th December 1959 by the Assistant Chief Engineer of Vickers-Armstrongs (Aircraft) Ltd. This will not appear in the JOURNAL and two copies are held in the Library for consultation there or borrowing.

Fundamentals of Guided Missiles. U.S.A.F. Air Training Command and Technical Staff. Aero Publishers, Los Angeles. 1960. 573 pp. Illustrated. 12.50 dollars. *To be reviewed.*

History of Metals, A. Vols. I and II. L. Aitchison. Macdonald and Evans, London. 1960. 648 pp. Illustrated. £8 8s. 0d. (2 vols.) *To be reviewed.*

I.A.L. Handbook of Aircraft Data. International Aeradio Limited, Southall. 1959. 47 pp. No price given. Compiled and edited by G. R. Stroud, A.F.R.Ae.S., this gives, in tabular form, details of aircraft at present in use that are likely to be required by airport administration. Copies may be bought from the publishers direct.

Incompressible Aerodynamics. Bryan Thwaites. Oxford University Press, London. 1960. 636 pp. Illustrated. 75s. *To be reviewed.*

Les Activités Economiques de L'O.A.C.I. dans les Trois Années a Venir. A Kotaite. C.S.T.A., Rome. 1960. 16 pp. No price. A paper by the President of the Air Transport Committee of I.C.A.O.

Nimonic High-Temperature Alloys, The. Engineering Data. Henry Wiggin and Co. Ltd., Birmingham. 1960. 52 pp. No price. A sixth edition of one of the well-known prestige publications of this firm. Anyone interested should apply for a copy to Wiggin Street, Birmingham 18.

Proceedings of Ninth Annual Texas Agricultural Aviation Conference and Short Course on Pest Control. A. & M. College, Texas. 1960. No price quoted. Nineteen titles read at the Conference which was organised by four sponsors, all with agricultural interest, in Texas. The papers tend to be of narrow interest. "Why are some pink bollworms short cycle and others long cycle" is, perhaps, a typical question that is answered.

Proceedings of the Society for Experimental Stress Analysis. Vol. XVII, No. 1. C. V. Mahlmann and W. M. Murray (editors). S.E.S.A., Cambridge 39, Massachusetts. 1959. 180 pp. Illustrated. No price. *To be reviewed.*

Structural Aluminum Design. K. Angermayer. Reynolds Metals Co., Richmond 18, Va. 1958. 100 pp. Diagrams. No price. A remarkably informative booklet giving

design formulae for aluminium structures. The last 34 pages are data sheets of chemical composition, physical and mechanical properties, applications and limitations of aluminium alloys to American standard designations.

Symposium on Fretting Corrosion. American Society for Testing Materials, Philadelphia. 1953. 84 pp. Illustrated. 2.20 dollars. A rather old publication acquired as a result of a Library inquiry, it nevertheless is a useful and authoritative addition to a subject on which the Library has little material. Five papers by American authorities, with references and discussions.

Symposium on Ground Effect Phenomena. Princeton University. 1959. 391 pp. Illustrated. No price quoted. *To be reviewed.*

To Greece. W. G. McClymont. War History Branch, Dept. of Internal Affairs, Wellington, New Zealand. 1959. 538 pp. Illustrated. No price quoted. *To be reviewed.*

Transonic Wind Tunnel. Aircraft Research Association Ltd. 1956. 20 pp. Diagrams. No price. A booklet descriptive of the A.R.A. wind tunnel and illustrated by detail and general drawings. Lists are also given of the member firms, contractors and suppliers.

Turbulent Flows and Heat Transfer. Edited by C. C. Liu. Oxford University Press, London. 1960. 550 pp. Illustrated. 105s. *To be reviewed.*

S.A.E. PAPERS presented at the National Aeronautical Meeting, New York (5th-8th April 1960)

Paper No.

T39 Explosive forming. F. A. Cox and E. F. Mellinger.
T40 Future trends in materials removal techniques. M. E. Merchant.
T41 Theory and application of the plasma arc. R. M. Gage.
T42 Analysis of problems of oil film lubrication for bearings under space conditions. C. M. Apt and N. M. Wiederhorn.
154A The selection of accessory power systems for long-duration manned space vehicles. E. T. Raymond.
154B SNAP 2—a reactor powered turboelectric generator for space vehicles. G. M. Anderson.
154C Heat transfer problems of space vehicle power systems. R. A. Trusela and R. G. Clodfelter.
155A An integrated approach to the planning, evaluation, and control of capital facilities. C. W. Goldbeck.
156A Reducing the paper mill through methods and systems simplification. H. A. Helstrom.
156B Manufacturing expense controls. R. M. Lynas.
158A Basic studies on base-metal thermocouples. J. F. Potts and D. L. McElroy.
158B Materials for high (2,500°-4,000°F) gas engine temperature measurements. A. R. Anderson and D. J. MacKenzie.
158C A design procedure for thermocouple probes. L. B. Haig.
158D Experimental determination of thermocouple time constants with use of a variable turbulence, variable density wind tunnel, and the analytic evaluation of conduction, radiation, and other secondary effects. A. F. Wormser.
158E A stable high temperature thermometry rig. R. J. Moffat.
158F Intercomparison of thermocouple response data. F. R. Caldwell *et al.*
158G Dynamic testing of gas sampling thermocouples. J. D. Meador.
158H Time response characteristics of temperature sensors. M. D. Scadron.
159A Engineering standards for the comparison of direct electrical conversion devices. F. W. Anders.
159B A thermoelectric air conditioning module for sealed cabins. H. L. Hall and P. L. Catron.
159C The thermionic power converter and its applications. J. G. Leisenring.
159D Fuel cells—a technical and economic study. A. M. Moos.
159E High temperature fuel cells. E. A. DeZubay.
159F Solar concentration cells. B. H. Clampitt and D. E. German.
160A Applications and limitations of metal removal techniques in aircraft and missile manufacturing. M. Field.
160B Applications and limitations of new developments in metals joining processes. P. J. Rieppel.
160C Production application of high energy rate. E. W. Feddersen.
161A Process refractometer for continuous plant stream monitoring. D. D. Doran and Y. M. Chen.
162A Notes on the results of recent tests of a momentum exchange type silencer for turbojet engines. E. Stringas.
162B The design and development of the General Electric CJ805-3 thrust reverser and noise suppressor. W. S. Bertaux.
162C By-pass engine noise. F. B. Greatrex.
163B Boot-strap launching—a step toward simplified GSE. C. C. Worstell and W. A. Beck.
164A Acoustically induced fatigue cause, solution and design analysis. E. W. Thrall.
164B Resonant fatigue failures associated with noise. R. N. Bingman.
165A An interplanetary exploratory vehicle. W. E. Beall.
165B Nuclear space vehicles using pebble bed reactors. M. M. Levoy and J. J. Newgard.
165C Electric propulsion and power requirements for space vehicles. F. D. Stull and V. W. Shiel.
166A A new design approach for supersonic transports. C. L. Blake.
166B Shock wave noise of supersonic aircraft. I. L. Ryhming *et al.*
166C Supersonic air transports: an airline talks back. B. S. Shenstone.
167A Nuclear rockets for lifting manned stations into space. H. F. Crouch.
167B Choice of engine type for nuclear powered multi-purpose aircraft. D. P. Lalor and W. C. Schmill.
167C Some practical methods for fabricating shields for nuclear-powered aircraft. W. Q. Hullings and J. L. McDaniel.
168B Ceramic bodies and coatings for rocket engine applications. W. T. Monagle.
168C Structural and insulative characteristics of ablating plastics. F. A. Vassallo *et al.*
169A The nuclear powered airship. L. Jurich.
169B The potential of nuclear-powered aircraft for commercial cargo transport. J. F. Brady.
169C Flight reliability in nuclear aircraft. L. W. Credit.
170A Trends in navy turboprop/turboshaft engine developments. A. L. Rasmussen.
170B The Canadair 44—a breakthrough cargo aircraft. K. H. Larsson.
171A Performance and design criteria of an adaptive circuit proposed for a space re-entry vehicle. W. Beauchemin.
171B Minimum flyable handling qualities of airplanes. G. Bull.
171D Discussion of some design problems associated with artificial feel systems of airplanes with irreversible powered flight controls. T-Y Feng and D. C. Neil.
172A The turbofan engine and its application versatility. S. M. Taylor and C. B. Brame.
172B Aft fan engines for commercial transport. B. J. Gordon and R. C. Hawkins.
172C Turbofan and by-pass type engines for jet transports. A. A. Lombard and D. Gerdan.
173A Man and space. L. Carlyle.
173B Human engineering payoff. J. A. Macdonald.
173C Pilot instrumentation for vehicle control in near space. C. J. Hecker.
174A An analysis of V/STOL vehicles on a payload-range basis. J. H. Aydelotte.
174B Trends in VTOL aircraft propulsion system requirements. J. B. Nichols.
174C A high energy absorption landing gear for VTOL aircraft. C. L. Wharton.
175A Considerations of the rendezvous problems for space vehicles. J. C. Houbolt.
175B Adaptive control considerations for re-entry flight. J. W. Clark and J. H. Ahlberg.
176A Recent high temperature bearing developments. J. H. Johnson.
176B Recent developments in high temperature bearings and lubricants. P. C. Hanlon.
176C Development progress on gas bearings for airborne accessory equipment. C. R. Adams.
176D N.A.S.A. research on the high-temperature bearing problem. W. J. Anderson and E. E. Bisson.
177A What makes a high energy propellant? J. D. Clark.

Reports

AERODYNAMICS

BOUNDARY LAYER *see also* WINGS AND AEROFOILS

Measurements of the effect of surface cooling on boundary layer transition on a 15 degree cone. Part II. Tests at M=3 and M=4 in the 5 in. × 5 in. No. 5 wind tunnel at R.A.E. Farnborough. J. G. Woodley. C. P. 479. 1960.—(1.1.2.4).

Turbulent boundary layer on a yawed cone in a supersonic stream. W. H. Braun. N.A.S.A. T.R. R-7. 1959.
The momentum integral equations are derived for the boundary layer on an arbitrary curved surface, using a streamline co-ordinate system. Computations of the turbulent boundary layer on a slightly yawed cone are made for a Prandtl number of 0·729, wall to free stream temperature ratios of ½, 1 and 2, and Mach numbers from 1 to 4. Deflection of the fluid in the boundary layer from outer stream direction, local friction coefficient, displacement surface, lift coefficient, and pitching-moment coefficient are presented.—(1.1.3.4).

Boundary-layer displacement effects in air at Mach numbers of 6·8 and 9·6. M. H. Bertram. N.A.S.A. T.R. R-22. 1959.
Measurements are presented for boundary layer induced pressure gradients on a flat plate in air at a Mach number of 9·6 and for the drag of thin wings at a Mach number of 6·8 and zero angle of attack. The investigation was conducted in the Langley 11-inch hypersonic tunnel, and the pressure measurements at a Mach number of 9·6 were made in the presence of substantial heat transfer from the boundary layer to the wall.—(1.1.1.4×1.10.2.2×1.9.1×1.2.3).

Skin-friction measurements in incompressible flow. D. W. Smith and J. H. Walker. N.A.S.A. T.R. R-26. 1959.
Experiments have been conducted to measure the local surface shear stress and the average skin friction coefficient in incompressible flow for a turbulent boundary layer on a smooth flat plate having zero pressure gradient. Data were obtained for a range of Reynolds numbers from 1 to 45 million. The local surface shear stress was measured by a floating-element skin friction balance and also by a calibrated total head tube located on the surface of the test wall. The average skin friction coefficient was obtained from boundary layer velocity profiles.—(1.1.3.1).

An analysis of ablation-shield requirements for manned reentry vehicles. L. Roberts. N.A.S.A. T.R. R-62. 1960.
The problem of sublimation of material and accumulation of heat in an ablation shield is analysed and the results are applied to the re-entry of manned vehicles into the earth's atmosphere. The parameters which control the amount of sublimation and the temperature distribution within the ablation shield are determined and presented in a manner useful for engineering calculation.—(1.1.1.4×1.9.1×25.2).

Effects of unit Reynolds number, nose bluntness, and roughness on boundary layer transition. J. L. Potter and J. D. Whitfield. A.E.D.C.-T.R.-60-5. March 1960. Presented at the AGARD Boundary Layer Research Meeting, London, April 1960.
Factors affecting transition and the effects of unit Reynolds number and very small degrees of leading edge bluntness are discussed. A means of estimating the effect of roughness on boundary layer transition is suggested.—(1.1.2).

Boundary-layer measurements on 15-deg and 24·5-deg cones at small angles of incidence M=3·17 and 3·82 and zero heat transfer. F. V. Davies and R. J. Monaghan. R. & M. 3133. 1959.—(1.1.1.4×1.1.2.4×1.1.3.4).

Experiments, with and without air jets, on an N.A.C.A. 64A006 semi-wing having 50° sweepback on the leading edge. R. A. Wallis and N. Ruglen. A.R.L. Report A.113. July 1959.
Low speed wind tunnel tests have disclosed the type of flow problem which must be faced when attempting to improve the stalling behaviour of thin swept wings. Discrete air jets have been used successfully in the vicinity of the wing leading edge for the purposes of controlling laminar separation, and delaying turbulent separation.—(1.1.4.1).

COMPRESSIBLE FLOW *see also* BOUNDARY LAYER
THERMO-AERODYNAMICS
WINGS AND AEROFOILS

The effect of fuselage modifications on the zero-lift transonic drag of a fighter aircraft (Hunter F.Mk.1) as measured by free-flight model tests. G. H. Greenwood. C.P. 482. 1960.
Free-flight model tests have been conducted on three 1/10th scale models of the Hawker Hunter F.Mk.1 aircraft to investigate the effect of body shaping on zero-lift transonic drag. The models were: unmodified aircraft; the aircraft modified by a rear fuselage fairing only, based upon a restricted application of the design method of Küchemann; and the aircraft modified by a complete fairing according to the sonic area rule.—(1.2.2×1.12.2).

Approximate analytical solutions for hypersonic flow over slender power law bodies. H. Mirels. N.A.S.A. T.R. R-15. 1959.
Approximate analytical solutions are presented for two-dimensional and axisymmetric hypersonic flow over slender power law bodies. Both zero order and first order solutions are presented. These solutions are compared with exact numerical integrations of the equations of motion and appear to be accurate particularly when the shock is relatively close to the body.—(1.2.3.1).

A method of solution with tabulated results for the attached oblique shock-wave system for surfaces at various angles of attack, sweep, and dihedral in an equilibrium real gas including the atmosphere. R. L. Trimpi and R. A. Jones. N.A.S.A. T.R. R-63. 1960.
A new method of solution is derived from basic physical considerations. Results are tabulated for the following ranges: angle of attack, 0° to 65°; angle of sweep, 0° to 75°; angle of dihedral, 0° to 30°; Mach number, 3 to 30; and "effective specific-heat ratio" parameter, 1·10 to 1·67. Both the method and tabulated solutions are easily adaptable to flight in any gas or in the atmosphere of any planet. An illustrative example is presented based on the 1956 A.R.D.C. model atmosphere.—(1.2.3.2×1.10.1.2).

Shock-wave structure based on Ikenberry-Truesdell approach to kinetic theory of gases. R. E. Street. N.A.S.A. T.N. D-365. Feb. 1960.—(1.2.3.2).

The effect on the drag of a wing-body combination of moment-of-area-rule modifications with pods ducted to simulate engine nacelles. R. R. Dickey and L. L. Levy. N.A.S.A. T.N. D-308. Feb. 1960.
The zero lift drag of a basic wing-body combination with an elliptic plan form wing of aspect ratio 3·0 and of the basic model with two separate moment of area rule modifications was measured at Mach numbers from 0·6 to 1·4. The two modified models were identical except that the inboard pods of one of the models were ducted to simulate engine nacelles with internal compression-type inlets.—(1.2.2×1.5).

On the one-dimensional overtaking of a shock wave by a rarefaction wave. I. I. Glass et al. *U.T.I.A. T.N. 30. July 1959.*
Solutions in closed form are given for the overtaking of a shock wave by a rarefaction wave. The equations have been solved on a digital computer and the results are presented graphically.—(1.2.3.2×1.12.1.3×1.5.1.4).

CONTROLS *see* WINGS AND AEROFOILS

FLUID DYNAMICS

The two-dimensional flow of an ideal dissociating gas. J. W. Cleaver. C.o.A. Report 123. Dec. 1959.
The ideal "oxygen-like" gas has been used and in all cases the internal modes of the molecules are assumed to be instantaneously adjusted to be in equilibrium with each other. A brief introduction to the ideal dissociating gas and the rate equation is given and then the partial differential equations governing the motion of this ideal gas are treated by a standard characteristic method. As an application of the method

developed the flow field around a sharp corner of an ideal dissociating gas is examined and a limited investigation of the free stream conditions and expansion angle on the resulting relaxation zone is given.—(1.4.1).

The oscillating plate in magnetohydrodynamics. J. A. Steketee. U.T.I.A. Report 63. *Aug.* 1959.
The classical problem of the oscillating plane in a viscous incompressible fluid is extended to a fluid which is conductive while in addition there is a magnetic field perpendicular to the plane. There are two penetration depths which depend on the intensity of the applied magnetic field.—(1.4.4).

INTERNAL FLOW *see also* COMPRESSIBLE FLOW
AEROELASTICITY

Theoretische und experimentelle Untersuchungen an Querstromgebläsen. R. Coester. Inst. für Aero. Zurich. Mitt. 28. 1959. *In German*—(1.5.3).

LOADS *see* WINGS AND AEROFOILS
AEROELASTICITY
STRUCTURES—LOADS

STABILITY AND CONTROL *see also* MISSILES

The longitudinal frequency response to elevator of an aircraft over the short period frequency range. D. M. Ridland. C.P. 476. 1960.
Formulae for the evaluation of aircraft longitudinal frequency response characteristics are presented. The simple short period frequency response is illustrated for three different types of aircraft and the effects of neglecting elevator lift and speed variations associated with the phugoid motion are separately determined and discussed.—(1.8.2.1).

On the design of a high-gain saturating control system for use as an adaptive autopilot. J. D. McLean and S. F. Schmidt. N.A.S.A. T.N. D-305. *Feb.* 1960.
Analytical methods are presented for predicting the frequency, amplitude, and effect on performance of the inherent limit cycle or "chatter." Methods are also given for reducing the chatter amplitude and its undesirable effects on the low-frequency response.—(1.8.0.1 × 18.1)

*Equations of motion of a rocket-powered aircraft. A. Miele. Boeing Doc. D*1-82-0038. *Jan.* 1960.—(1.8.0.1).

An investigation of the hydrodynamic stability and spray characteristics of high length/beam ratio seaplane hulls with high beam loadings. D. M. Ridland et al. *R. & M.* 3095. 1959.
Tests have been made on a series of high length/beam ratio seaplane hulls with high beam loadings. The effects of varying the hull parameters, forebody warp, afterbody length and afterbody angle, together with the interaction of these effects, and of tailoring the afterbody, on the calm water hydrodynamic stability and spray characteristics of the series have been determined. Investigations have been made into the effects of load, moment of inertia and radius of gyration, and slipstream, together with a limited assessment of longitudinal hydrodynamic stability characteristics in waves. Dynamic models were used and tests for the main investigation consisted of assessments of longitudinal hydrodynamic stability characteristics, both undisturbed and disturbed, at two weights, of spray behaviour at these weights, and of directional hydrodynamic stability characteristics at the higher weight only. Improvements in test techniques are described.—(1.8.2.2 × 17.1 × 3.10).

THERMO-AERODYNAMICS *see also* BOUNDARY LAYER

On the sudden contact between a hot gas and a cold solid. J. F. Clarke. C.o.A. Report 124. *Jan.* 1960.
The flow induced by the sudden contact between a semi-infinite expanse of gas and a solid, initially at different temperatures, is examined on the basis of a linear continuum theory.—(1.9.1 × 1.2.3.2).

An elementary study of gas injection and sublimation into a simple shear layer. J. F. Clarke. C.o.A. Report 126. *Feb.* 1960.
The injection of a foreign gas into a simple shear layer is examined and the results extended to the case for which the wall material sublimes under the action of heat transferred through the layer. This simplified analysis serves to emphasise some of the processes and parameters involved in more rigorous treatments of this type of ablation.—(1.9.1).

Ablation studies of low melting point bodies in a pre-heated supersonic air stream. J. W. Cleaver and F. Thomson. C.o.A. Report 127. *Feb.* 1960.
The melting of axi-symmetric and two-dimensional bodies at a Mach number of 1·78 and stagnation temperatures up to 550°K was investigated. Preliminary tests were also made with a two-dimensional wedge model.—(1.9.1).

*An exact solution to a problem in kinetic heating. C. H. J. Johnson. A.R.L. Note M.E.*236. *Aug.* 1959.
An exact solution is given to the problem of determining the temperature distribution in a heat conducting half-space subsequent to the impulsive motion in a direction parallel to the surface of a constant property fluid lying over it.—(1.9).

WINGS AND AEROFOILS *see also* BOUNDARY LAYER
COMPRESSIBLE FLOW
FLIGHT TESTING
PROPELLERS

The centre section shape of swept tapered wings with a linear chordwise load distribution. J. C. Cooke. C.P. 470. 1960.
The method of Weber is used to find the shape of the centre section of a swept tapered wing to produce a load distribution which changes linearly from unity at the leading edge to zero at the trailing edge along any chord. An approximation for this distribution is used in order to make the integrals tractable. These integrals are evaluated and the downwash calculated. A reasonably accurate approximate formula for the downwash is derived, and the results are illustrated by a few examples, giving downwash and angles of twist.—(1.10.1.2 × 1.6.1).

An investigation of the flow over a half-wing model with 60·5 *degree leading edge sweepback at high subsonic and supersonic speeds. F. O'Hara and J. B. Scott-Wilson. C.P.* 471. 1960.
Pressure measurements and surface oil flow observations have been made in the N.A.E. 3 ft. tunnel on a half-wing model with 60·5° leading edge sweepback, of aspect ratio 2·828, taper ratio 0·333, and section 6 per cent R.A.E. 101, at Mach numbers 0·81, 1·42, 1·61 and 1·82.—(1.10.2.2 × 1.6.1).

Brief experiments on a flapped aerofoil having a cusped cavity and a blowing jet at the cusp. A. D. Wood. N.R.C. Report L.R.-269. *Dec.* 1959.—(1.10.1.1 × 1.3.4 × 1.1.6.1).

On the application of wing projected area distributions to the design of wing-fuselage combinations at supersonic speeds. B. M. Ryan. Douglas Report S.M.-23765. *Dec.* 1959.
The average area distribution of a delta wing with simple thickness distribution is found and the wing combined with fuselages in various wing volume to fuselage volume ratios such that the combination of the average wing plus fuselage area distributions has a Sears-Haack shape. Such fuselages are optimum, *i.e.* the fuselage is supersonically area-ruled such that the wing-body combination has minimum wave drag. The results are general over the supersonic Mach number range and may be scaled by an adjustment of the streamwise dimensions. Wing-fuselage combinations are drawn for a Mach number of 1·414 and wing thickness of 8·5 per cent and then scaled to a Mach number of 3 which results in a wing thickness of 3 per cent.—(1.10.1.2 × 1.2.3.1).

Methods of computing average projected area distributions of wing thickness for supersonic area ruling of wing-body combinations. B. M. Ryan. Douglas Report S.M.-23791. *Dec.* 1959.
Several variations of an approximate method of computing the average projected area distribution of an elliptical wing with optimum thickness distribution are studied here and compared with an exact analytical method developed by R. M. Licher. The "best" method is chosen and applied to delta wings with double wedge and modified double wedge profiles. Drags are not computed.—(1.10.1.2 × 1.2.3.1).

*The transonic characteristics of a family of two-dimensional symmetrical double wedge profiles. Part II: Results obtained for lifting profiles. R. J. Sandeman. A.R.L. Report A.*115. *Aug.* 1959.
Results obtained from pressure distributions and strain gauge

force measurements are presented for four two-dimensional symmetrical double wedge profiles with leading edge semi-angles of 3·4°, 4·5°, 7·5°, and 9·7° at incidences up to 4° and free stream Mach number to just above one.—(1.10.2.1).

TESTING AND INSTRUMENTS *see also* COMPRESSIBLE FLOW
MISSILES
SCIENCE-GENERAL

*Free-flight experiments on the measurement of free-stream static pressure at transonic speeds with particular reference to the Mk.9 pitot-static head. C. Kell. C.P.*475. 1960.
The problem of measuring ambient static pressure at Mach numbers between 0·8 and 1·4 is dealt with; free-flight measurements of the pressures ahead of bodies of revolution with noses of various shapes are dealt with. The results indicate the minimum distances ahead of blunt-nosed bodies at which the errors in static pressure measurements are small enough to be acceptable. Errors introduced by the static-pressure measuring heads themselves are dealt with; tests on the standard Mk.9 pitot-static head are described and results presented. 1.12.5×1.12.2×13).

An investigation of support interference on AGARD calibration model B. C. J. Schueler. A.E.D.C.-T.N.-60-35. *Feb.* 1960.
Tests were conducted in a 12-inch supersonic wind tunnel to determine the critical sting length for AGARD Calibration Model B with a sting-to-body diameter ratio of 0·3. The tests were made at $M=2$, 3 and 4 and a Reynolds number range of $3·5\times10^6$ to $13·5\times10^6$ based on body length.—(1.12.1.3).

*Variation of the temperature coefficient of a group of strain gauges. G. J. Saleeba and I. G. Scott. A.R.L. Note S.M.*260. *Oct.* 1959.
Measurements of the temperature coefficient of resistance of twenty strain gauges of the same type show wide variation in the values obtained.—(1.12.6.2×33.3.1).

AEROELASTICITY

See also STRUCTURES—LOADS

The aerodynamic derivatives of an aerofoil oscillating in an infinite staggered cascade. A. H. Craven. C.o.A. Report 125. *Jan.* 1960.
Thin aerofoil theory is used to obtain, in integral form, the aerodynamic derivatives of an aerofoil oscillating in an infinite cascade. The theory allows for arbitrary stagger angle and phase difference between adjacent blades of the cascade. The expressions obtained reduce, for zero stagger and for in-phase and antiphase oscillations, to known results.—(2×1.6.3×1.5.4.1).

AIRCRAFT

See AERODYNAMICS—STABILITY AND CONTROL
ANIMAL FLIGHT
AVIATION MEDICINE
FATIGUE

DESIGN AND CONSTRUCTION

See INSTRUMENTS AND EQUIPMENT

AIRCRAFT OPERATION

See also POWER PLANTS
STRUCTURES—LOADS

*Pilot opinions and practices on the approach to landing: a questionary survey among Australian civil and military pilots. J. C. Lane and R. W. Cumming. A.R.L. Report H.E.*1. *April* 1959.
Two questionnaires, one to airline and military pilots and one to instructors, yielded much information on pilot opinions and practices on the approach to landing.—(5.1).

ANIMAL FLIGHT

The aerodynamics of soaring bird flight. I. N. Vinogradov. R.A.E. Lib. Trans. 846. 1951.
The structure and basic muscular mechanism of birds and how they achieve flight is discussed. Tests and measurements made on living and model birds are reported. The method of boundary layer control achieved by the arrangement of the feathers in a bird's wing and the complex deflections of the wing involved in producing thrust and maintaining stability and control are emphasised. Where possible mathematical analysis of the phenomena is given and test apparatus and measurements are described in detail. The question of muscular flight by man is briefly considered.—(7×3.8).

EXTRA-ATMOSPHERIC TECHNOLOGY

See also ELECTRONICS

The motion of a rotating satellite of cylindrical shape in the atmosphere. P. Notni and H. Oleak. R.A.E. Lib. Trans. 868. 1959.
Formulae are derived for a very long rotating satellite of cylindrical shape, which enable the acceleration in the orbit and the lengthening of the rotation period to be computed. Formulae are given for the precession of the axis of rotation.—(8.2×25.2).

AVIATION MEDICINE

Medical and human engineering aspects of flight in Ryan V.T.O.L. and S.T.O.L. aircraft. P. F. Girard. AGARD Report 239. *May* 1959.
A short historical outline including brief descriptions of the Ryan V.T.O.L. aircraft is given. The major aspects of the principal medical and human factors in hovering and transitional flight are discussed, principal attention being given to the human engineering aspect. Presented at the Fourteenth Meeting of the Flight Test Techniques and Instrumentation Panel, May 1959, in Athens, Greece.—(9×3.12).

ELECTRONICS

Distribution of the electron concentration with height from the data of tests with rockets and artificial earth satellites and its influence on radio wave propagation. L. A. Zhekulin. R.A.E. Lib. Trans. 862. 1958.
A wave treatment is applied to the propagation of radio waves in the ionosphere. Approximations are made to the latest electron density profiles of the ionosphere, and the reflected waves are investigated after varying frequencies. The earth's magnetic field is neglected while the effects of collisions are included.—(11×8.2).

FLIGHT TESTING

See also AERODYNAMICS—TESTING AND INSTRUMENTS
FATIGUE

Stability-derivative determination from flight data. C. H. Wolowicz and E. C. Holleman. AGARD Report 224. *Oct.* 1958.
A discussion of factors, such as test techniques, determination of mass characteristics, instrumentation, and methods of analysis affecting the determination of stability and control derivatives from flight data is presented.—(13.2×1.10.0.2).

FUELS AND LUBRICANTS

Property requirements for liquid rocket propellants. E. M. Goodger. C.o.A. Note 97. *Nov.* 1959.
An analysis is made of the properties necessary for liquid rocket propellants to give effective performance with acceptable handling. Typical propellants are examined and their relative suitability assessed.—(14×27.3×34.1.1).

Lubrication of a rotating cylinder on a plane surface, considering cavitation. L. Floberg. Inst. Machine Elements, Chalmers Univ. Tech. Report 9. 1959.
The contact between a cylinder and a plane surface is hydrodynamically treated. The surfaces are rigid, and the viscosity of oil is assumed to be constant.—(14.2×23.1×17).

HYDRODYNAMICS

See also AERODYNAMICS—STABILITY AND CONTROL
FUELS AND LUBRICANTS

A method for calculation of hydrodynamic lift for submerged and planing rectangular lifting surfaces. K. L. Wadlin and K. W. Christopher. N.A.S.A. T.R. R-14. 1959.
A method is presented for the calculation of lift coefficients for rectangular lifting surfaces of aspect ratios from 0·125 to 10 operating at finite depths beneath the water surface, including the zero depth or planing condition. Theoretical values are compared with experimental values obtained at various depths

of submergence with lifting surfaces of aspect ratios from 0·125 to 10. The method can also be applied to hydrofoils with dihedral.—(17.1×17.2).

INSTRUMENTS AND EQUIPMENT

See also AERODYNAMICS—STABILITY AND CONTROL

The U.S.A.F. vertical instrument program. E. L. Brown. AGARD Report 236. *May* 1959.
A programme is described which set out to develop a control panel in which the display information is presented to the pilot in an interrelated and integrated form rather than as individual outputs of separate instruments.—(18.1 × 4.2.1).

MATERIALS

See also STRUCTURES—THEORY AND ANALYSIS

Thermal-stress fatigue cracking of turbine buckets operated at 1700°F in a turbojet engine with long periods of operation between starts. R. A. Signorelli et al. *N.A.S.A. T.N. D-272. Feb.* 1960.
Thermal stress fatigue resistance of alloys Sel-1, B. & B., forged Udimet 500, and Inconel 713 was studied at 1700°F in a J47 engine with an average of 11 hours at rated speed between starts. These data were compared with those of a previous investigation with an average of 1·4 hours of rated-speed operation between starts.—(21.2×31.2.2.7.1.8×27.1).

Mechanical properties of some heat-resistant metal honeycomb cores. E. W. Kuenzi and W. E. Jahnke. F.P.L. Report 1872. *Dec.* 1959.
The results of tests of commercially produced heat-resistant metal honeycomb cores for use in structural sandwich contruction are presented. Cores tested were made of four corrosion-resistant steels, a nickel-chromium alloy, and titanium. Properties evaluated were compressive strength at normal and elevated temperatures and shear properties at normal temperatures. Detailed descriptions of core materials and testing procedures are given.—(21.2.3).

*Étude de processus de germination dans la réaction de l'oxygène sur le cuivre aux températures élevées. F. Gronlund. Pubs. Sc. et Tech. N.T.*88. 1960. (*In French*).—(21.2.2).

*The influence of the thickness of the specimen on the mechanical properties in compression and in 3 point bending of glass fabric base plastic laminates at room temperature. A. Hartman. N.L.L.-T.N. M.*2033 *A. May* 1957.
For glass fabric base plastic laminates the influence of thickness variations between 1·5 and 4·5 mm. has been determined on the mechanical properties in compression and in 3 point bending, both under dry and under wet conditions. The glass fabrics used were Volan-A treated unidirectional weave Tyglass Y 221 and the 2×2 twill weave Tyglass Y 86. A cold setting polyester was used as resin.—(21.3.3).

MECHANICAL ENGINEERING

See also FUELS AND LUBRICANTS

The dynamic loading of spur gear teeth. J. H. Dunmore. C.o.A. Report 122. *Oct.* 1959.
A description of the first stage of some work on the dynamic loading of gear teeth is given. Particular reference is made to the instrumentation problems which were encountered, and to the measurement of the shape of the gears and their associated transmission errors. No attempt is made at a theoretical analysis of the results.—(23.2).

The centrally loaded partial journal bearing. B. Jakobsson and L. Floberg. Inst. Machine Elements. Chalmers Univ. Tech. Report 7. 1959.
Centrally loaded journal bearings of infinite and finite bearing width are dealt with. The position of the cavitation region has been determined and due consideration has been taken to this constant pressure zone in calculating the different quantities. —(23.1).

Experimental investigation of power loss in journal bearings, considering cavitation. L. Floberg. Inst. Machine Elements. Chalmers Univ. Tech. Report 8. 1959.
The experimental power loss in a journal bearing is compared with the theoretical value.—(23.1).

Torque distribution, power flow and zero output conditions of epicyclic gear trains. B. Jakobsson. Inst. Machine Elements, Chalmers Univ. Tech. Report 10. 1960.
The basic principles of epicyclic gear trains are demonstrated and discussed.—(23.2).

Beschleunigungsverlauf und gleichgewichtsdrehzahlen einfacher planetengetriebe nebst selbsthemmungsversuche. J. Stromblad. Inst. Machine Elements. Chalmers Univ. Tech. Report 11. 1960. (*In German*).
The calculation of accelerations and decelerations of the three shafts of a simple epicyclic gear train are dealt with.—(23.2).

MISSILES

See also AERODYNAMICS—BOUNDARY LAYER
EXTRA-ATMOSPHERIC TECHNOLOGY

*Determination of nonlinear pitching-moment characteristics of axially symmetric models from free-flight data. M. L. Rasmussen. N.A.S.A. T.N. D-*144. *Feb.* 1960.
An analysis is presented for the pitching and yawing motion of a symmetrical missile with a cubic restoring moment. A rapid method of estimating the cubic restoring moment coefficients from the observed frequency and amplitudes of two independent sets of free-flight data is developed and demonstrated.—(25.2× 1.8.0.1×1.12.2).

Missile structures and materials. E. Z. Gray. AGARD Report 218. *Oct.* 1958.
State of the art and recommended future research areas are discussed for missile structure with regard to material selection, design criteria, analysis, testing and reliability. Better environmental definition is emphasised and corresponding multi-environmental analyses and tests are required to optimise designs.—(25.4×33.2.3×21).

POWER PLANTS

See also FUELS AND LUBRICANTS
MATERIALS

*Crash-fire protection system for a J57 turbojet engine using water as a cooling and inerting agent. D. O. Black. N.A.S.A. T.N. D-*274. *Feb.* 1960.
A crash-fire protection system was designed to reduce the likelihood of ignition of crash-spilled fuel that may be ingested by a modified J-57 engine. Means were included for rapidly extinguishing the normal combustor flame and for cooling and inerting with water the hot engine parts likely to ignite engine-ingested fuel.—(27.1×5.3).

Nomographisches Verfahren zur Berechnung von Staustrahltriebwerken. O. Lutz, W. Buschulte und K. Mose. DFL-Bericht Nr. 113, 1959. (*In German*).—(27.1.1).

PROPELLERS

Theory of wings in slipstreams. H. S. Ribner. U.T.I.A. Report 60. *May* 1959.
A general potential theory has been developed for the aerodynamics of a wing in one (or more) slipstreams of arbitrary shape or position. The central idea, involving the use of a "reduced" potential within the slipstream jet, is representation of the flow by means of two distributions of vortices (or doublets): one over the wing and its wake, and the other over the jet boundary.—(29.9×1.10.1.2).

FATIGUE

See also STRUCTURES—THEORY AND ANALYSIS

Crack propagation in sheet material—some conclusions deduced from a combination of theory and experiment. D. Williams. C.P. 467. 1960.
Simple formulae are established for correlating the results for small flat sheet specimens under tension or cylindrical specimens under internal pressure, with those for larger but similar specimens, and for correlating results for a flat sheet with those for the corresponding (*i.e.* the same flat sheet rolled into a cylinder) cylindrical sheet under the same tension produced by internal pressure.—(31.2.2.1.1.6×33.2.4.5.1×33.2.4.3.7).

Fatigue loadings in flight-loads in the tailplane of a Devon. A. Burns. C.P. 472. 1960.
Data are presented on the number of load cycles of various magnitudes occurring in the tailplane of a Devon in normal ground and flight conditions. The conditions include take-off, landing and taxying on grass and on metalled surfaces, and flight in turbulence.—(31.2.4.3×3.6×13.3).

SCIENCE—GENERAL

Quantitative Schlieren interferometry in wind tunnels. C. Renet. R.A.E. Lib. Trans. 874. *Feb.* 1960.
The utilisation of interferometric methods enables the indications obtained by Schlieren techniques, hitherto purely qualitative, to be rendered quantitative and capable of precise analysis. The apparatus is insensitive to vibration and is easily installed and adjusted.—(32.2.4×1.12.1.3).

Metrological applications of Schlieren interferometry. M. Philbert. R.A.E. Lib. Trans. 881. *Feb.* 1960.
The application of Schlieren interferometry to wind tunnel measurements and to the optical inspection of high quality mirrors and observation windows is discussed and equipment developed for these purposes is briefly described. Two methods of analysis of the plates are explained and illustrated by examples.—(32.2.4×1.12.1.3).

*A stereoscopic Schlieren system. T. A. Thomson. A.R.L. Note A.*175. *June* 1959.
A stereoscopic Schlieren system of 8 inch aperture was built for the Supersonics Laboratory at the University of Sydney. It enables the location in three dimensions of disturbances in compressible flow to be established and its employment in experimental studies indicates that the system is a useful addition to the techniques of flow visualisation.—(32.2.4×1.12.1.3).

Sur la stabilité des solutions colloidales en présence d'électrolytes. G. Watelle-Marion. Pubs. Sc. et Tech. N.T. 87. 1960. *In French*—(32.1).

STRUCTURES

LOADS *see also* THEORY AND ANALYSIS

Effect of the proximity of the wing first-bending frequency and the short-period frequency on the airplane dynamic-response factor. C. R. Huss and J. J. Donegan. N.A.S.A. T.R. R-12. 1959.
The results are presented in the form of preliminary design charts which can be used to estimate the first order effects of the addition of a wing-bending degree of freedom on the short period dynamic-response factor and on the maximum dynamic-response factor when compared with the steady-state response of the system.—(33.1.2×1.6.2×2).

Correlation of noise pressures and of the induced strains in an aircraft structure. B. L. Clarkson. U.S.A.A. Report 108. *Dec.* 1959.
The characteristics of the noise pressure correlation in the region surrounding a jet exhaust are outlined. In the near field of the jet it is necessary to rely on experimentally determined values of correlation. A preliminary investigation into the multimodal type of vibration taking place in a tailplane structure excited by jet noise is described. Strain correlation measurements indicate the mode of vibration at each resonant frequency.—(33.1.2×5.6).

A design philosophy for repeated thermal loading. E. W. Parkes. AGARD Report 213. *Oct.* 1958.
The elastic and inelastic behaviour of some simple structures subjected to cyclic thermal loading is discussed. The results are considered in relation to possible definitions of structural safety.—(33.1×33.2.4.0.9×33.2.2).

THEORY AND ANALYSIS *see also* MATERIALS
MISSILES
FATIGUE
STRUCTURES—LOADS

*The internal damping due to structural joints and techniques for general damping measurement. D. J. Mead. C.P.*452. 1959.
The source of damping in riveted or bolted joints which are subjected to harmonically varying loads is discussed in qualitative terms. Owing to the complicated nature of the source, an analytical determination of the damping properties of a joint is not deemed feasible, but from characteristics of the joint which may be obtained experimentally, a method is suggested of predicting the structural damping coefficient of a simple structure, vibrating in a known mode and at a known frequency.—(33.2.4.13.10×33.1.2).

Effect of a stringer on the stress concentration due to a crack in a thin sheet. J. L. Sanders. N.A.S.A. T.R. R-13. 1959.
A coefficient is obtained for determining the effect of a reinforcing stringer on the stress concentration factor at the tip of a crack in a thin sheet. The results are given for the case in which the stringer is intact and for the case in which the stringer is broken. In the first case the stress concentration factor for the stringer is also given.—(33.2.4.6×31.1.2.1.2.1.5).

Simply supported sandwich beam: a nonlinear theory. J. J. Zahn. F.P.L. Report 2157. *Sept.* 1959.
Stresses in a simply-supported sandwich beam under symmetric loading are obtained by a nonlinear theory. With the assumption of anti-plane core, the differential equations of equilibrium of the core are solved for core displacements in terms of four infinite sequences of integration constants. The facings are treated as cylindrically bent thin plates subject to large deflections. Stresses and displacements are matched at the interfaces of core and facings and the resulting non-linear differential equation are solved by Fourier analysis. A single example is worked out for the case of a central load and the results are shown in a series of curves.—(33.2.4.1×21.2.3×21.3.6).

Structural sandwich design criteria. E. W. Kuenzi. F.P.L. Report 2161. *Oct.* 1959.
Design criteria for structural sandwich constructions under various types of loading are presented. Detailed design procedures are presented for determining deflections of sandwich beams or panels and buckling of sandwich columns and simply-supported panels under edge load, including formulae for calculating facing stresses and core shear stresses. Methods of test for evaluating certain material properties are discussed briefly.—(33.2.4.14×21.2.3×21.3.6).

Some effects of internal heat sources on the design of flight structures. G. E. A. Thomann and R. B. Erb. AGARD Report 208. *Oct.* 1958.
A survey is given of the problems which arise due to heating of a structure. The magnitude and accuracy of the heat sources and their effects on the structure are discussed. This is followed by a more complete assessment of the engine-bay problem, its heating, structural effects and design considerations. The analytical treatments of the transient and steady-state temperature distributions are given, as well as an analysis of the thermal stresses in a typical jet engine bay structure. —(33.2.3.0.9×21.2×34.3).

TESTING *see* AERODYNAMICS—TESTING AND INSTRUMENTS

THERMODYNAMICS

See also FUELS AND LUBRICANTS
STRUCTURES—THEORY AND ANALYSIS

Graphical presentation of difference solutions for transient radial heat conduction in hollow cylinders with heat transfer at the inner radius and finite slabs with heat transfer at one boundary. J. E. Hatch. N.A.S.A. T.R. R-56. 1960.
Non-dimensional temperature distributions for transient radial heat conduction through hollow cylinders and one-dimensional heat conduction in slabs of finite thickness are presented in graphical form for a range of heat input.—(34.3.3).

Suitability of carbon resistors for field measurements of temperatures in the range of 35° *to* 100°*R. A. C. Herr* et al. *N.A.S.A. T.N. D*-264. *Feb.* 1960.
Material is presented for using a carbon composition resistor to measure temperature in the range of 35° to 100°R to an accuracy of one per cent of the absolute temperature. The important characteristics of the resistor as a sensing element are discussed together with circuitry especially suited to field-type instrumentation.—(34.2.1).